MUNI
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05 Climate models

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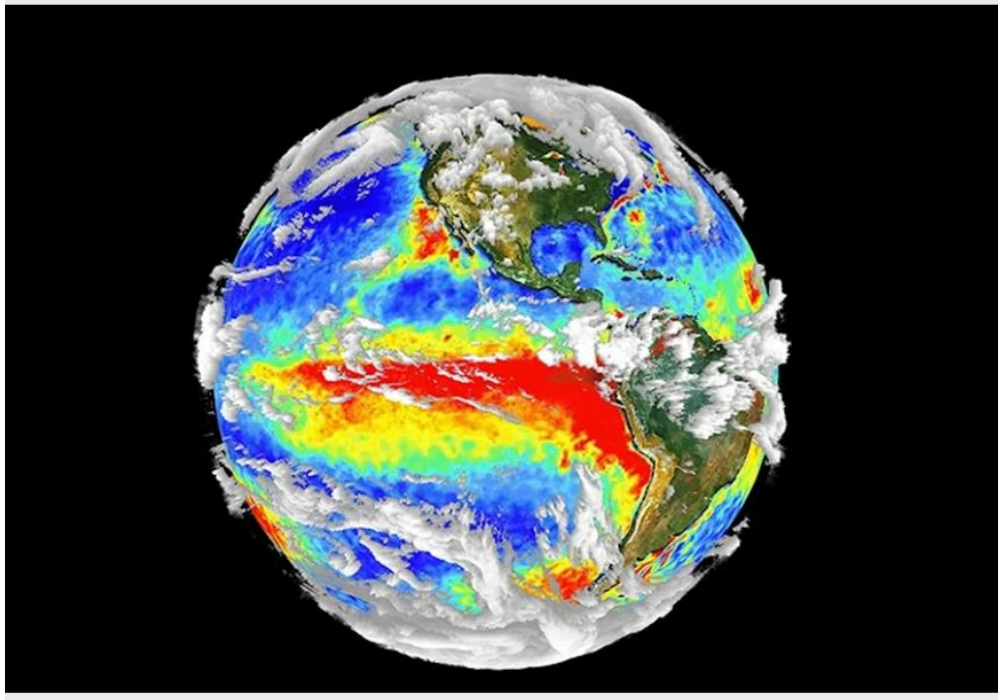
Content

1. Climate models
2. Emission scenarios
3. Climate change scenarios

What is a climate model?

- **quantitative mathematical description** of aspects of the Earth's **climate system** based on **physical, chemical** and **biological** properties of its components, its **interactions** and **feedback** processes



Purpose of a climate model

- increase our understanding of **how the climate system works**
- **simulate past climate fluctuations** to help interpret historical and paleo observations
- **simulate the future climate** based on scenarios for emissions of GHGs

Climate projections - to better inform decisions of national, regional, and local importance (water resource management, agriculture, transportation, and urban planning)

Climate models

Primitive equations for climate models

$$\frac{\partial U}{\partial t} = -U\frac{\partial U}{\partial x} - V\frac{\partial U}{\partial y} - \omega\frac{\partial U}{\partial P} + fV - \frac{\partial \Phi}{\partial x} + F_x$$

$$\frac{\partial V}{\partial t} = -U\frac{\partial V}{\partial x} - V\frac{\partial V}{\partial y} - \omega\frac{\partial V}{\partial P} - fU - \frac{\partial \Phi}{\partial y} + F_y$$

$$\frac{\partial \Phi}{\partial P} = -\frac{RT}{P}$$ ← Hydrostatic Balance

$$\frac{\partial U}{\partial x} + \frac{\partial V}{\partial y} + \frac{\partial \omega}{\partial P} = 0$$

$$\frac{\partial T}{\partial t} = -U\frac{\partial T}{\partial x} - V\frac{\partial T}{\partial y} + \omega\left(\frac{RT}{c_p P} - \frac{\partial T}{\partial P}\right) + \boxed{\frac{H}{c_p}}$$

$$\frac{\partial q}{\partial t} = -U\frac{\partial q}{\partial x} - V\frac{\partial q}{\partial y} - \omega\frac{\partial q}{\partial P} + e - p$$

U, V, and omega are the three components of the wind (in pressure coordinates.

T is temperature, P is pressure, q is specific humidity, F is friction (surface drag and momentum transport of unresolved eddies)

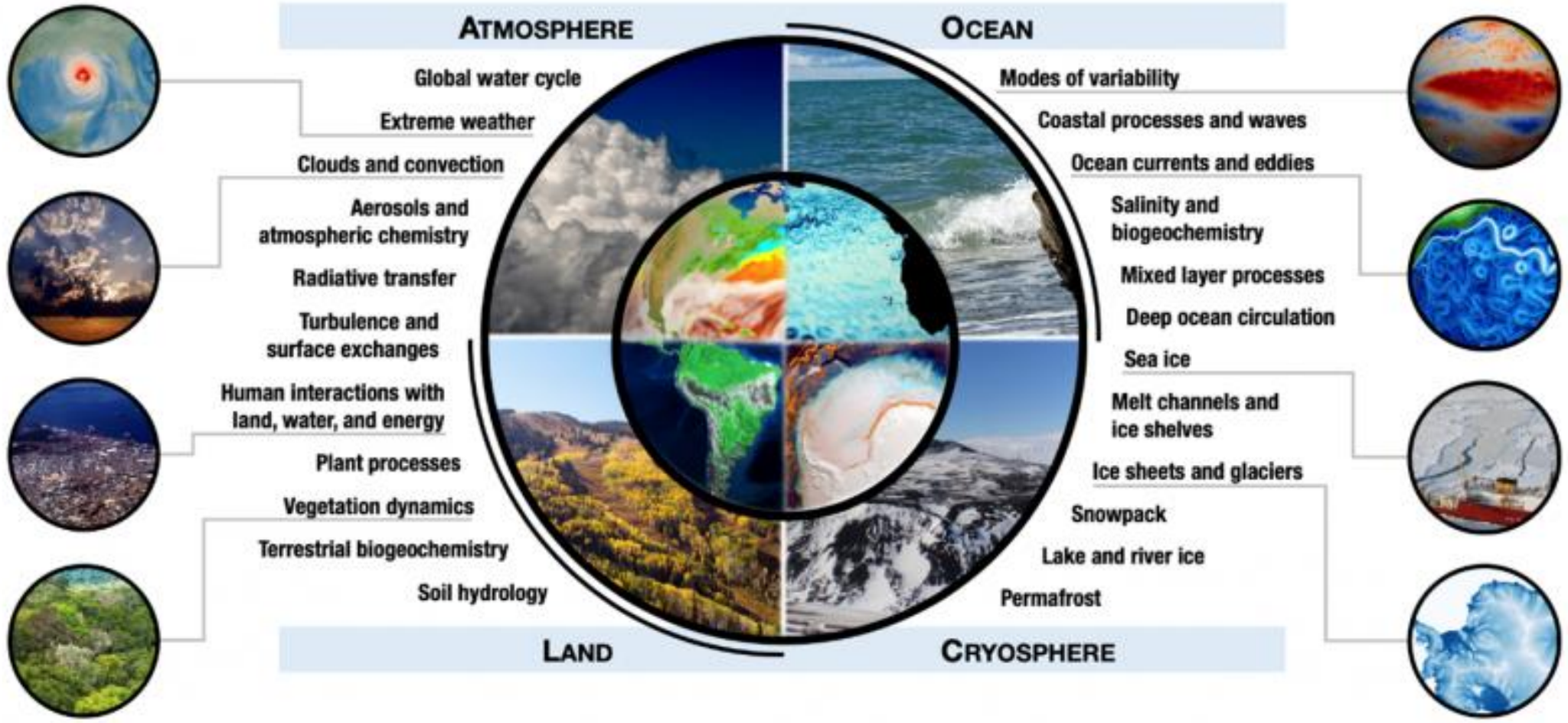
R is the dry air gas constant, c_p is the heat capacity at constant pressure, e is the net evaporation, and p is the net precipitation

H is the net diabatic heating term, and H=H_L + H_c + H_r + H_s

where H_L=latent heating from condensation/evaporation
H_c=heating caused by convection/vertical motion
H_r=radiative heating
H_s=sensible heating from the Earth's surface

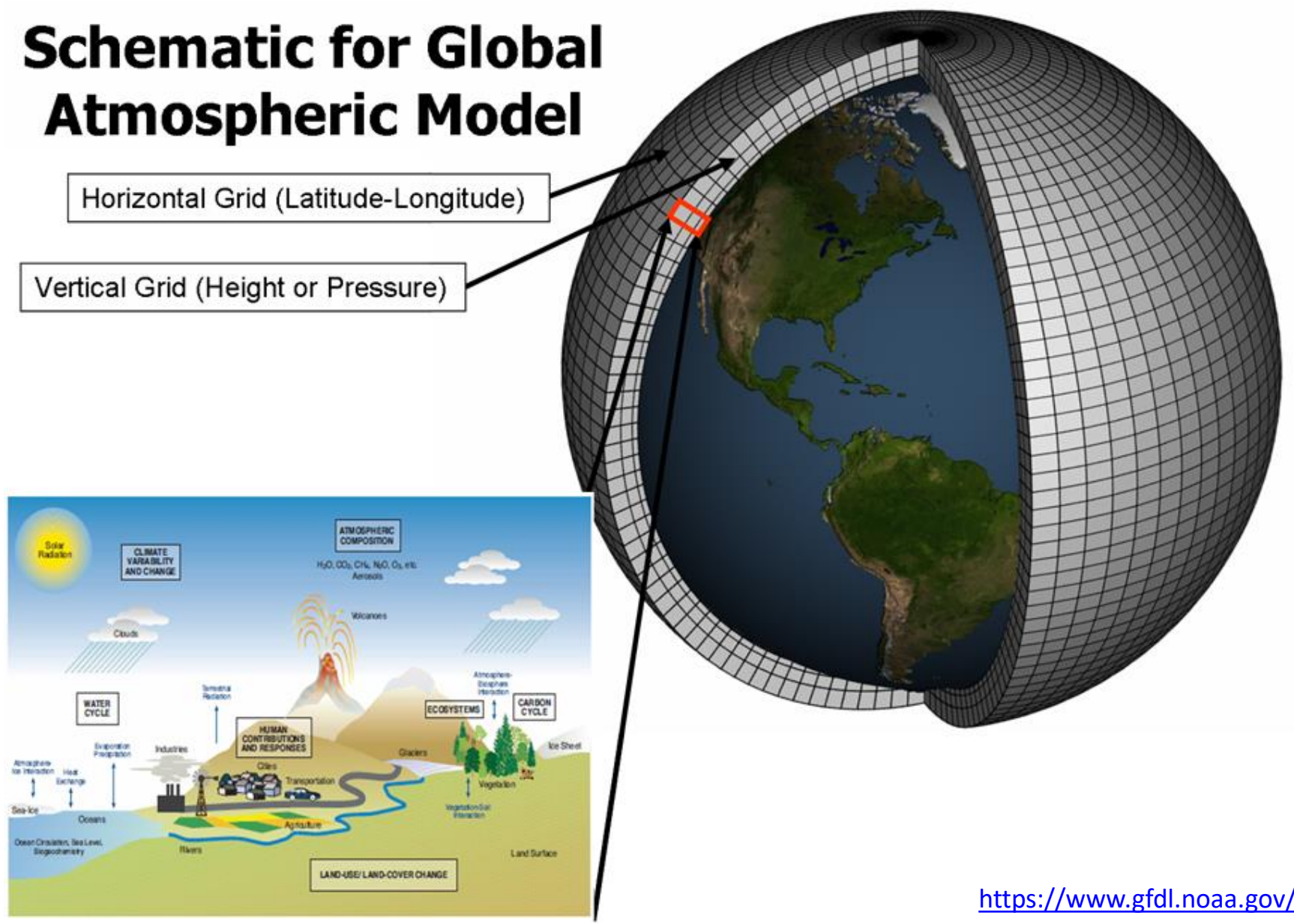
Climate models

The climate system components



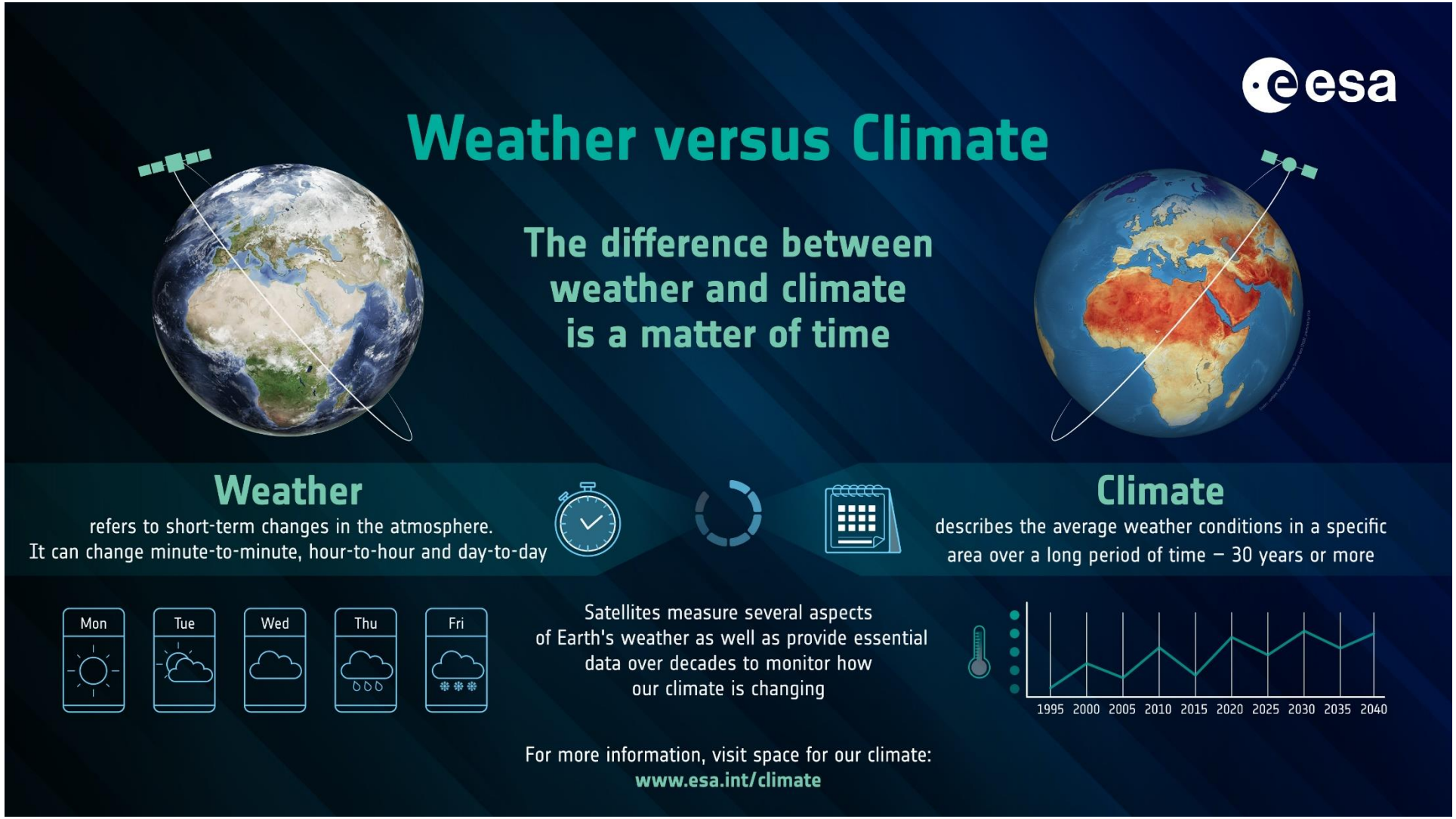
https://www.energy.gov/science/doe-explainsearth-system-and-climate-models

Climate models



https://www.gfdl.noaa.gov/climate-modeling/

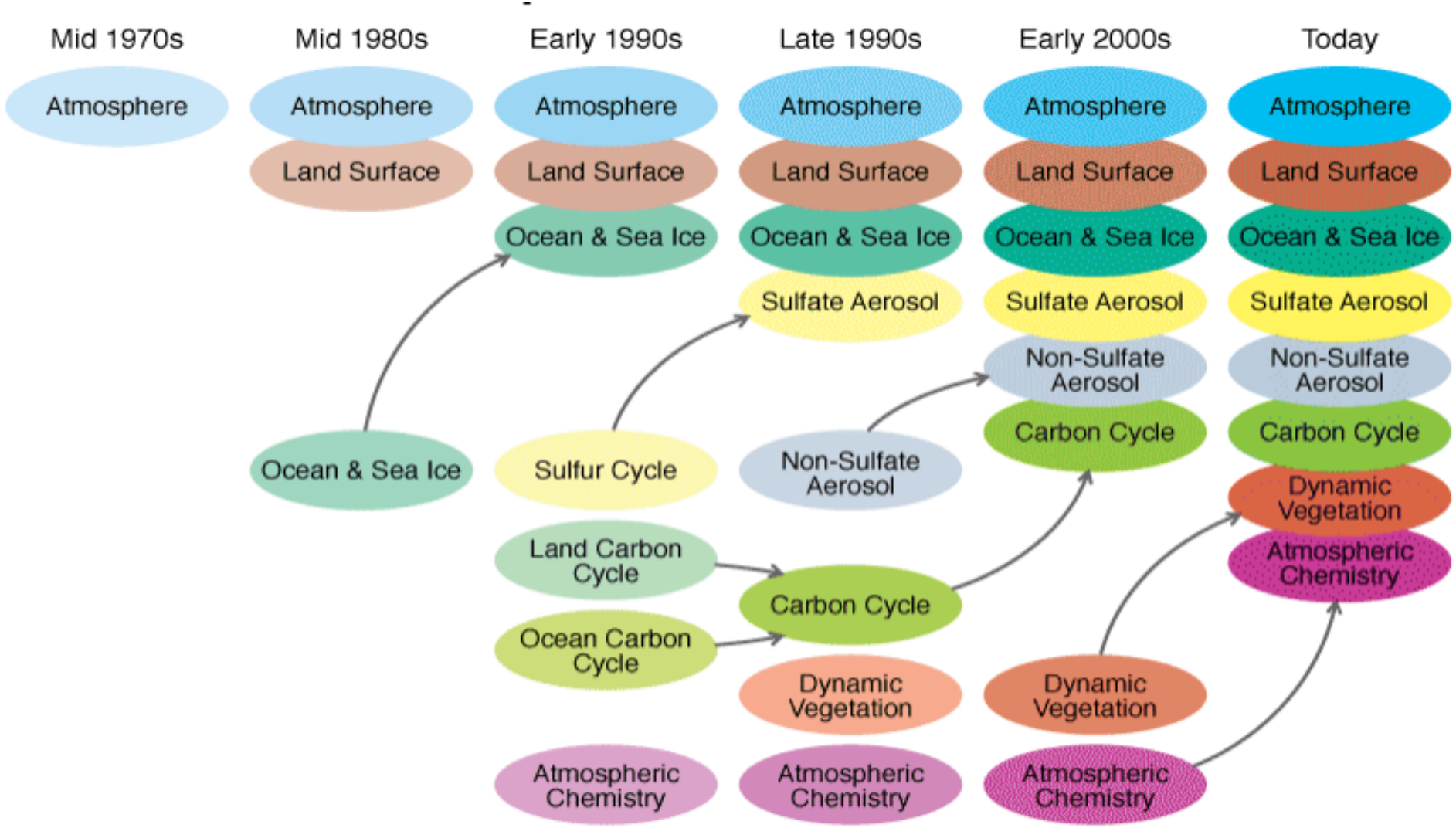
Weather vs climate models



https://blogs.reading.ac.uk/weather-and-climate-at-reading/2022/weather-vs-climate-prediction/

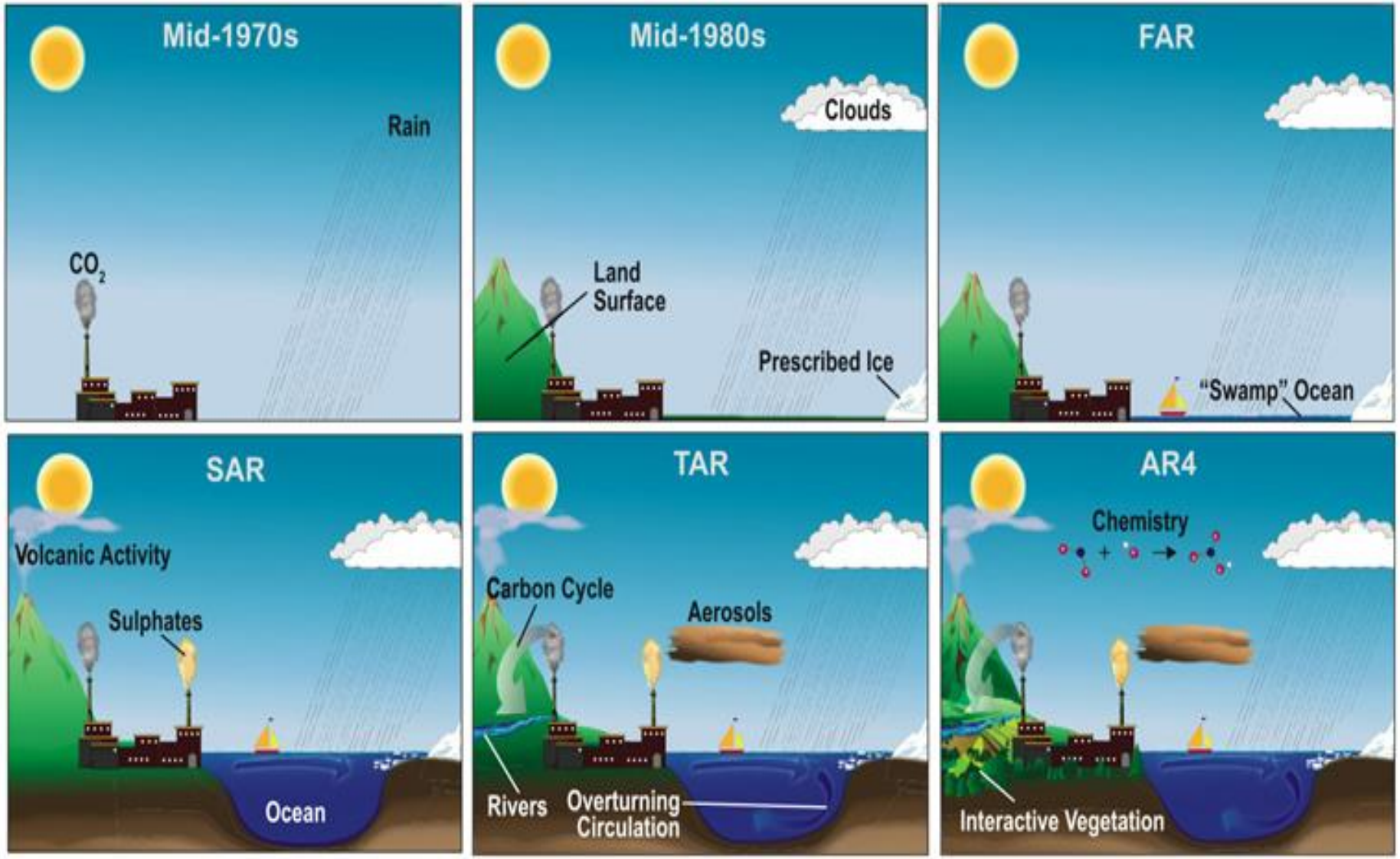
https://www.youtube.com/watch?v=Pn3ZKB1XLiQ

Development of climate models



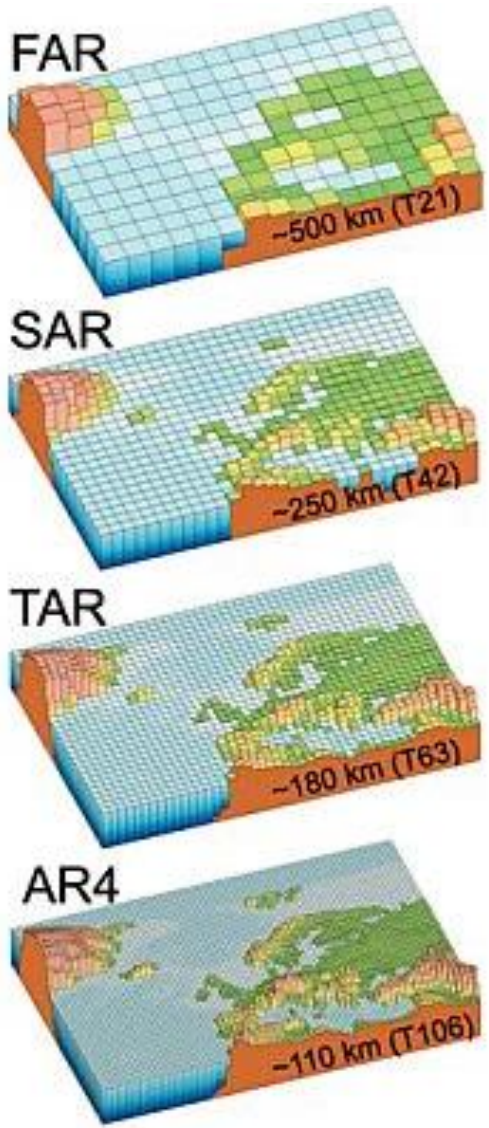
https://bookdown.org/floriandierickx/bookdown-demo/climate-data-from-models.html

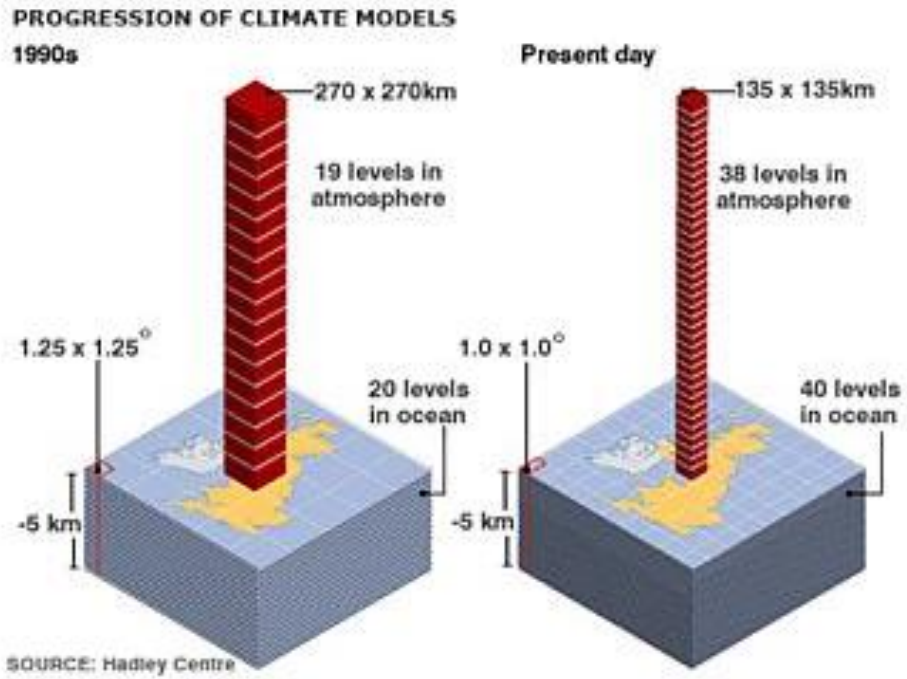
Complexity of climate models



https://bookdown.org/floriandierickx/bookdown-demo/climate-data-from-models.html

Spatial and Temporal Resolution





AR5: ~70km maximum horizontal resolution; up to 90 layers in the atmosphere and over 60 in the ocean.

https://bookdown.org/floriandierickx/bookdown-demo/climate-data-from-models.html

Types of climate models

1. **Global Climate/Circulation Model (GCM), Earth System Model (ESM)**
   - simulate the climate of the whole world
2. **Regional Climate Model (RCM)**
   - simulate the climate only for a part of the world

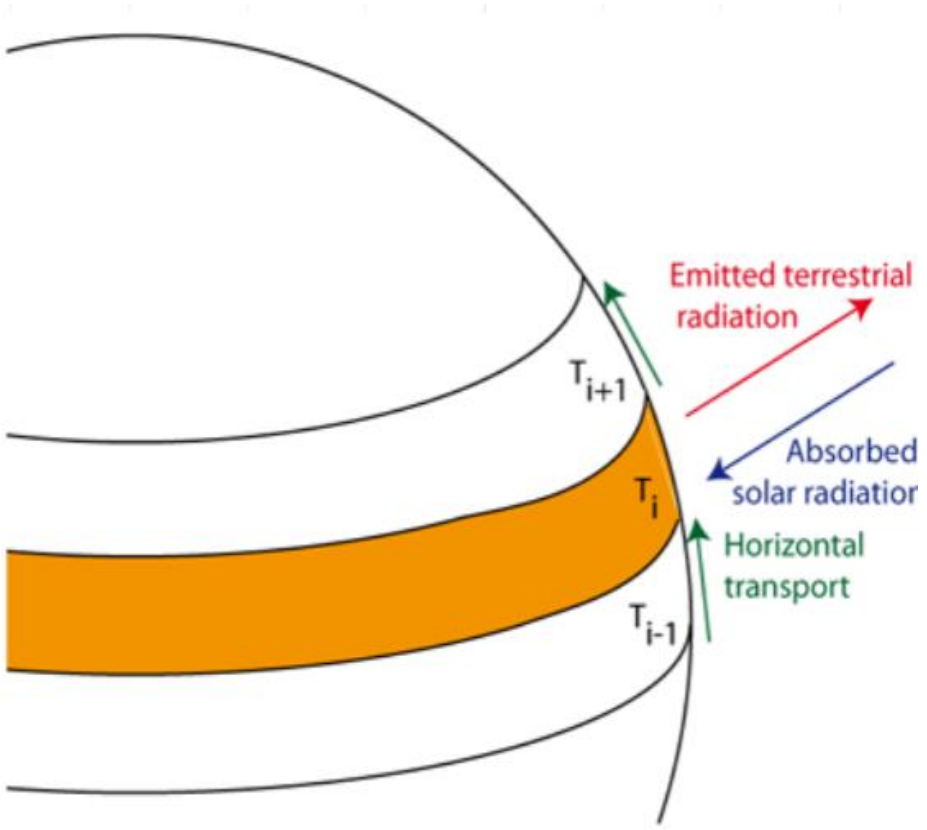
Models with more or less complexity/coupling:

1. **Atmospheric** models
2. **Coupled** models (ocean and atmosphere)
3. **Earth System** models (couple even more systems)
4. **Specific** climate models

EBM – Energy Balance Model

- analysis of the energy budget of the Earth
- basic processes and feedbacks
- a large degree of parameterization
- zero-dimensional EBMs

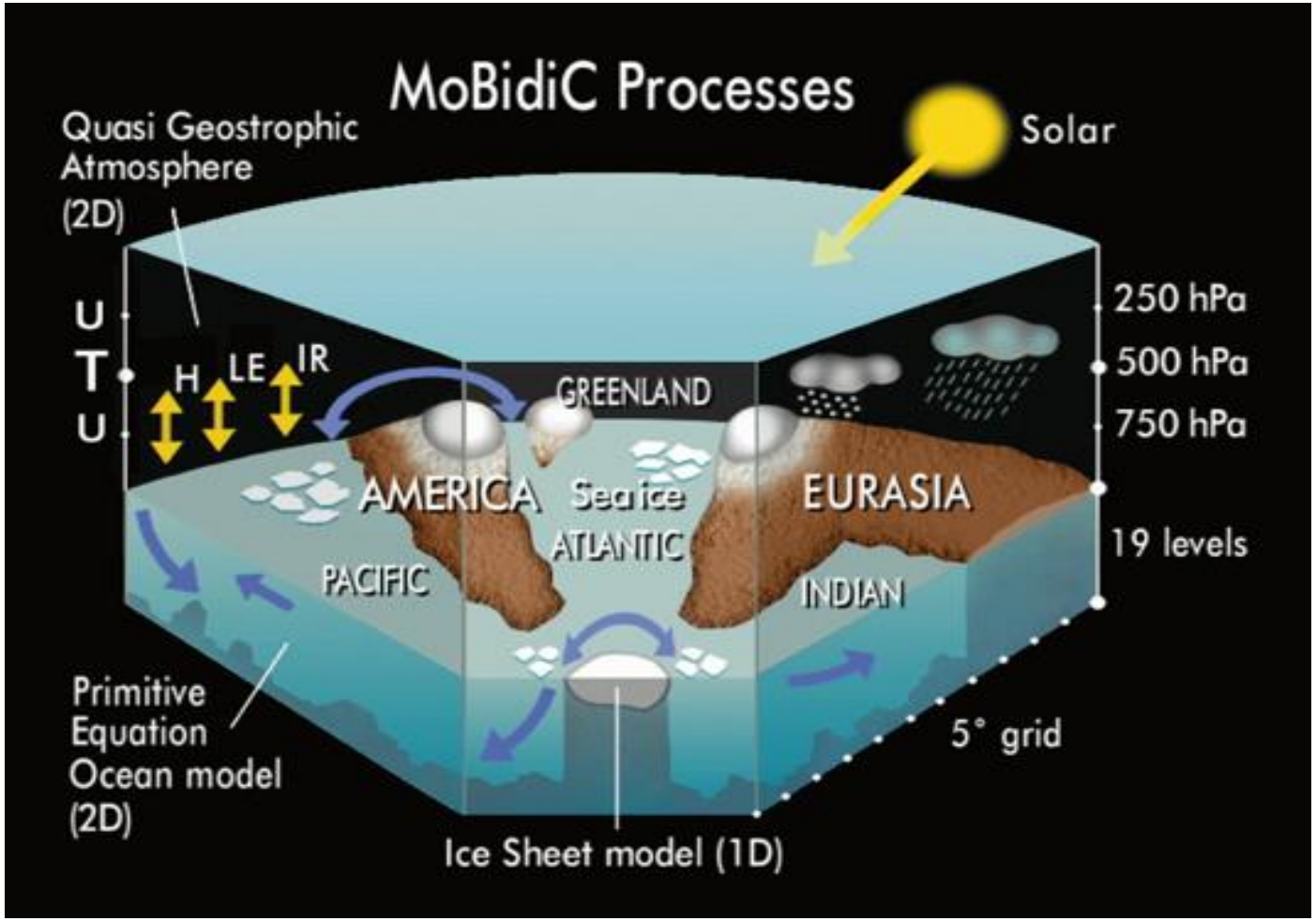
Parametrization - some processes are not explicitly included in models because of simplifications, lack of knowledge of the mechanisms, or because the spatial resolution of the model is not high enough to include them. They are represented by parameterisations in models.



http://www.climate.be/textbook/chapter3_node6.xml

EMIC - Earth Model of Intermediate Complexity

- including the geography of the Earth
- grid size 300–1000 km

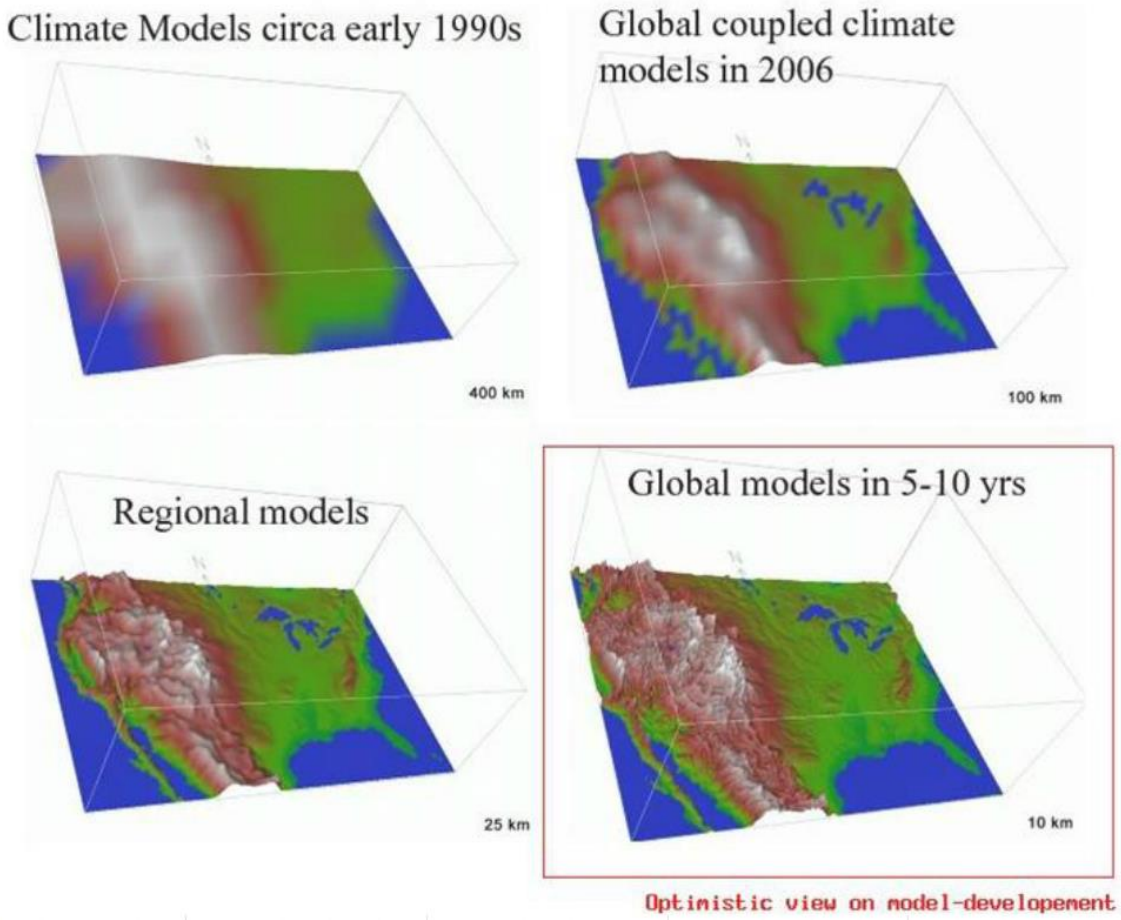


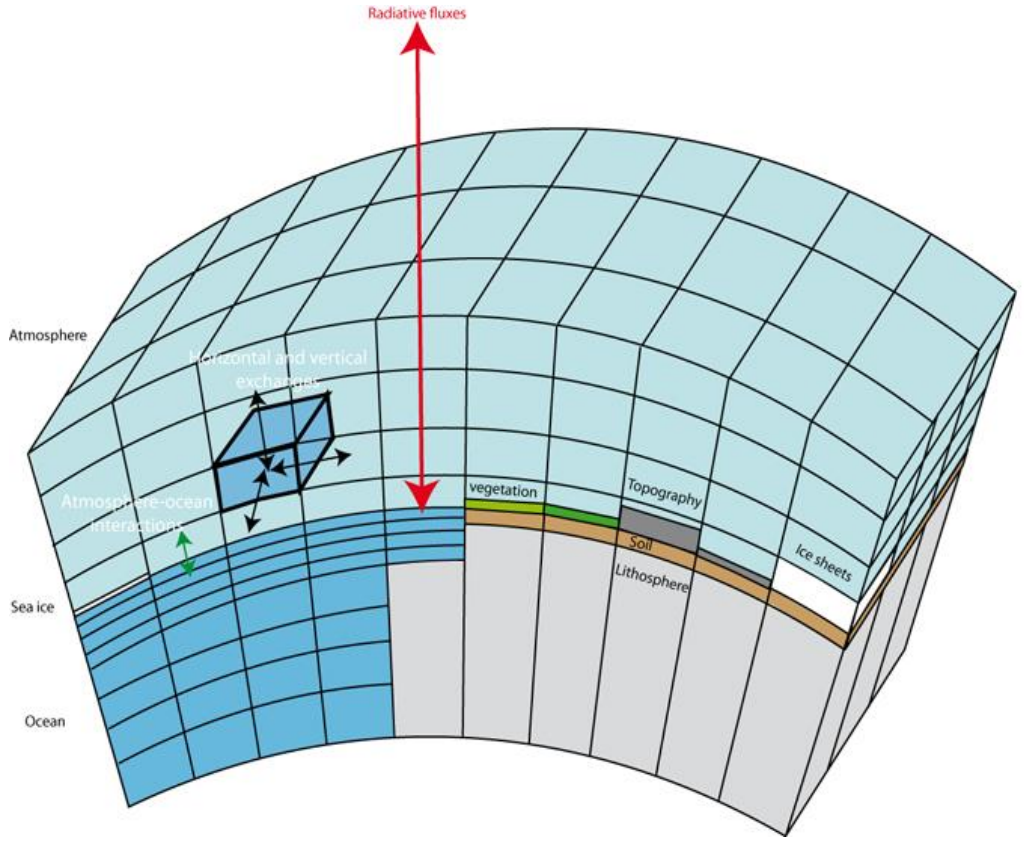
http://www.climate.be/textbook/chapter3_node7.html

GCM – General Circulation Model

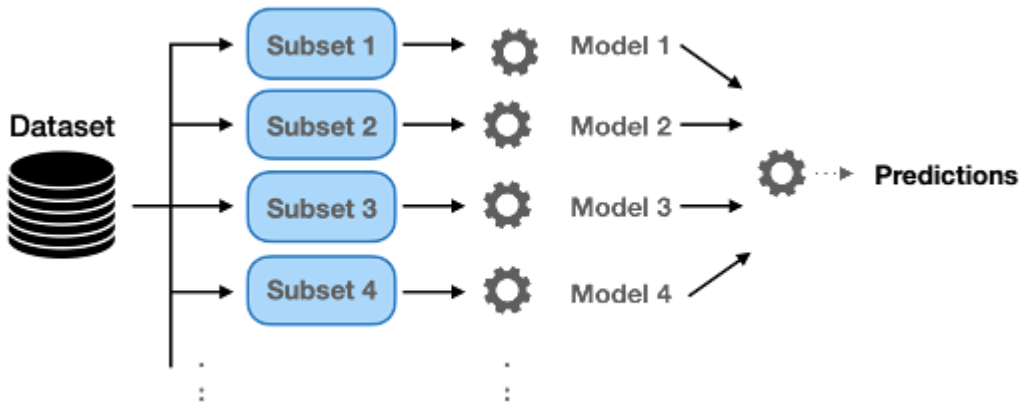
grid size 100-200 km

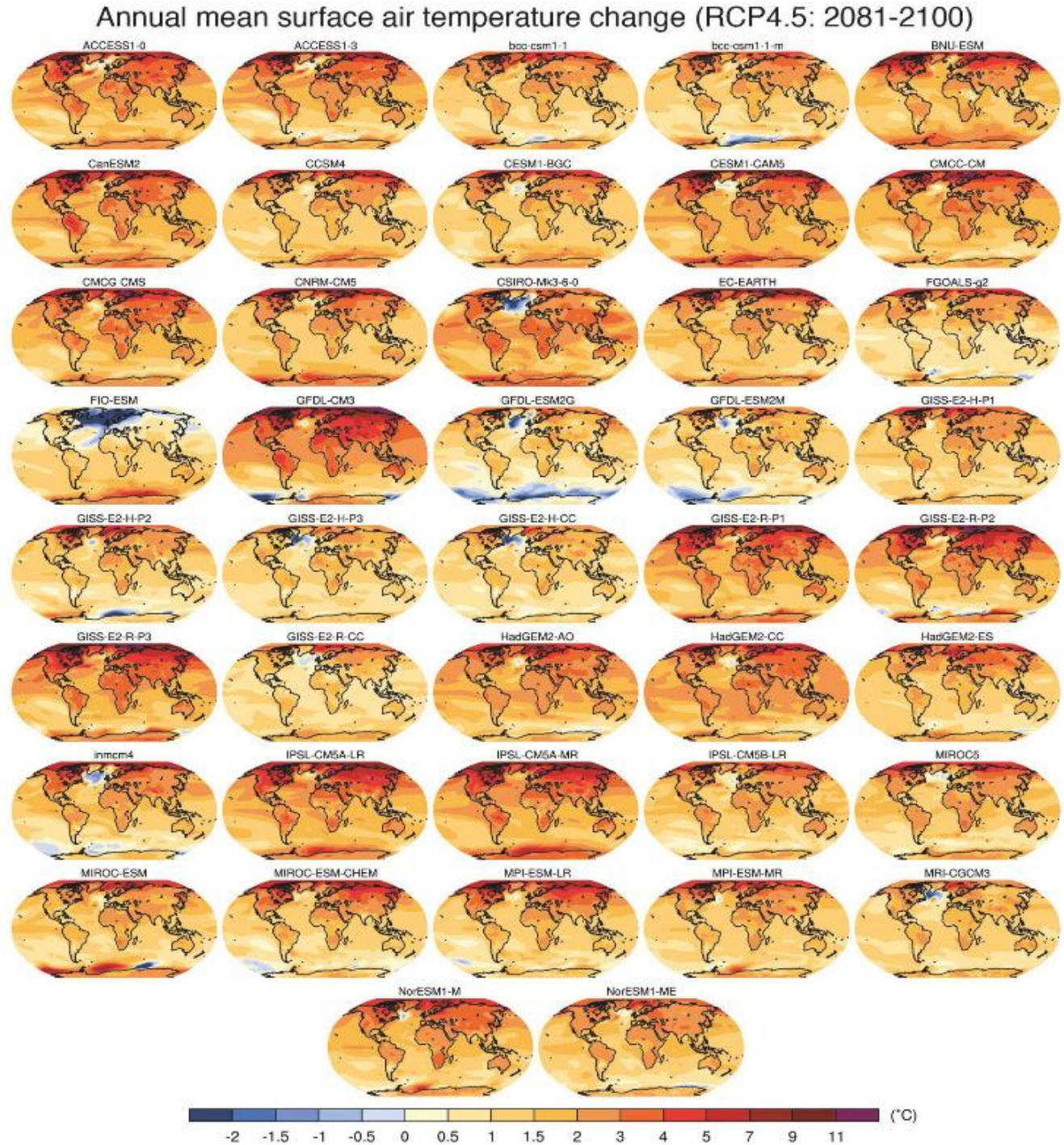
more detailed information on a regional scale





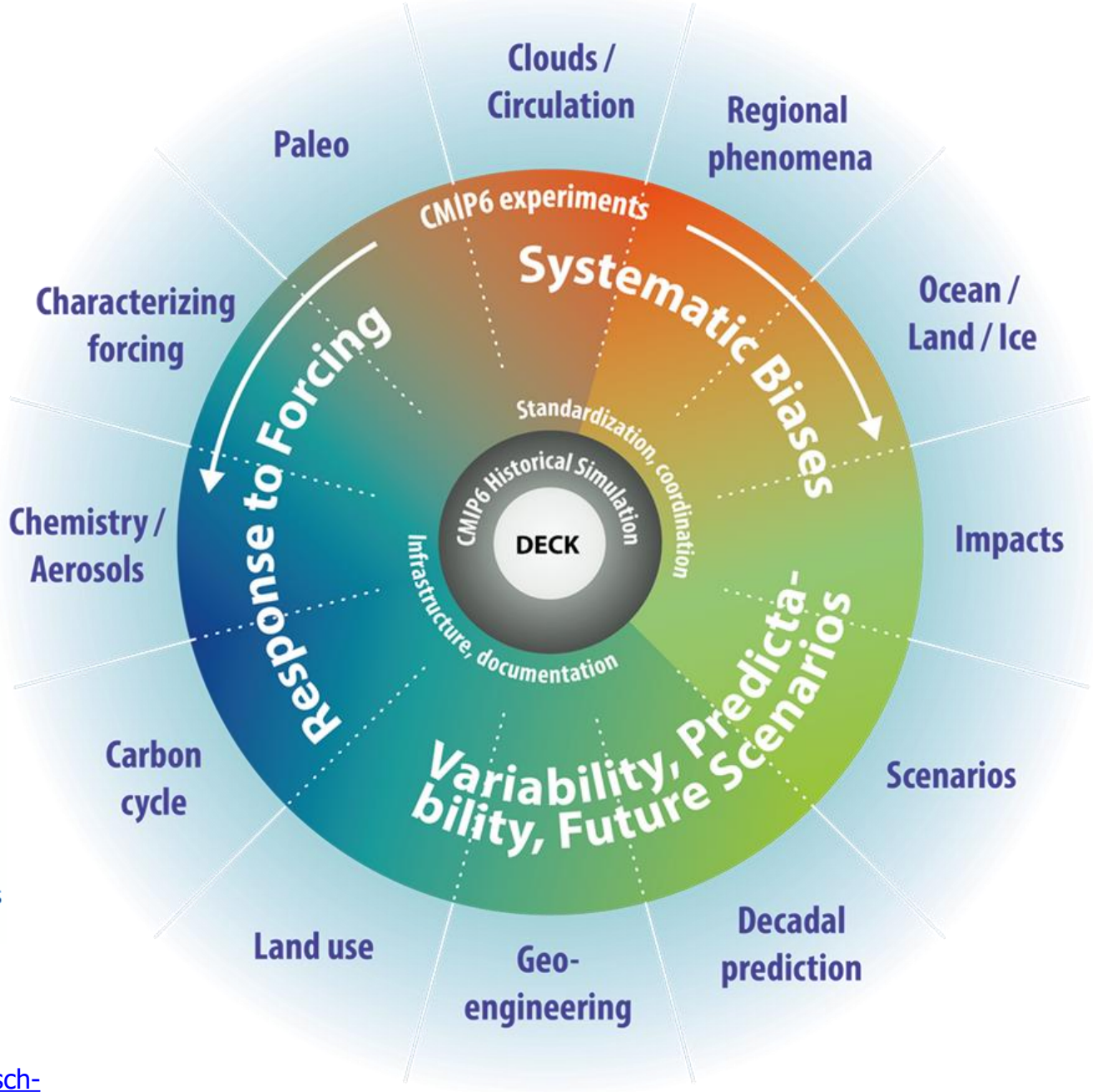
Multi-model ensemble





Earth system model

- **CMIP6:** The Coupled Model Intercomparison Project



CMIP6: Participating Model Groups

	Institution	Country		Institution	Country		Institution	Country
1	AWI	Germany	12	DOE	USA	23	MRI	Japan
2	BCC	China	13	EC-Earth-Cons	Europe	24	NASA-GISS	USA
3	BNU	China	14	FGOALS	China	25	NCAR	USA
4	CAMS	China	15	FIO-RONM	China	26	NCC	Norway
5	CasESM	China	16	INM	Russia	27	NERC	UK
6	CCCma	Canada	17	INPE	Brazil	28	NIMS-KMA	Republic of Korea
7	CCCR-IITM	India	18	IPSL	France	29	NOAA-GFDL	USA
8	CMCC	Italy	19	MESSY-Cons	Germany	30	NUIST	China
9	CNRM	France	20	MIROC	Japan	31	TaiESM	Taiwan, China
10	CSIR-CSIRO	South Africa	21	MOHC	UK	32	THU	China
11	CSIRO-BOM	Australia	22	MPI-M	Germany	33	Seoul Nat.Uni	Republic of Korea

CSIRO also contributed to CMIP5 using two previous versions of ACCESS (v1.0 and v1.3). In a comparison of ACCESS models against other CMIP5-contributed models, ACCESS performed very well:

https://mpimet.mpg.de/en/science/projects/integrated-activities/translate-to-englisch-cmip6-das-gekoppelte-modellvergleichsprojekt

Global (GCMs) vs Regional climate models (RCMs)

RCMs

- use global model outputs as boundary conditions to calculate conditions in limited (smaller) areas with higher spatial resolution
- significantly lower reliability.

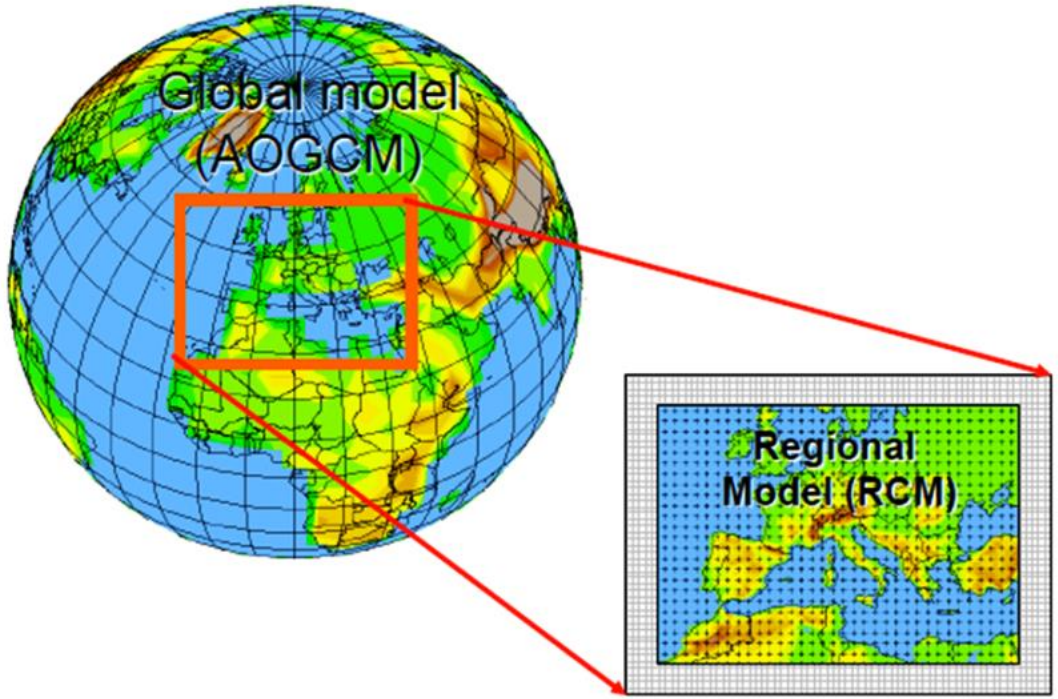


Fig. 1: Regional climate downscaling provides greater detail at local and regional scales, which is vital to improving analyses of vulnerability, impact and adaptation

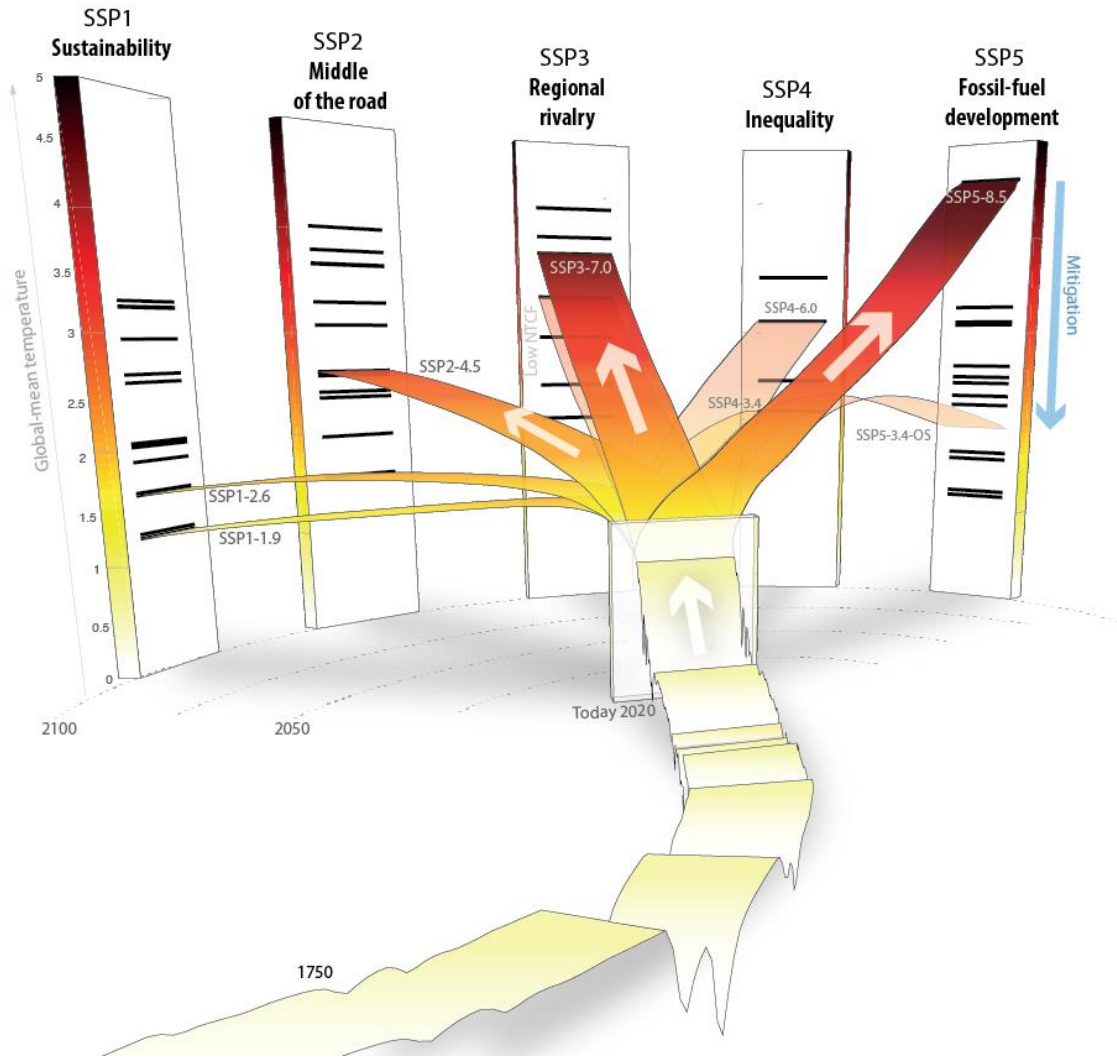
(Illustration courtesy of Justin Glisan)

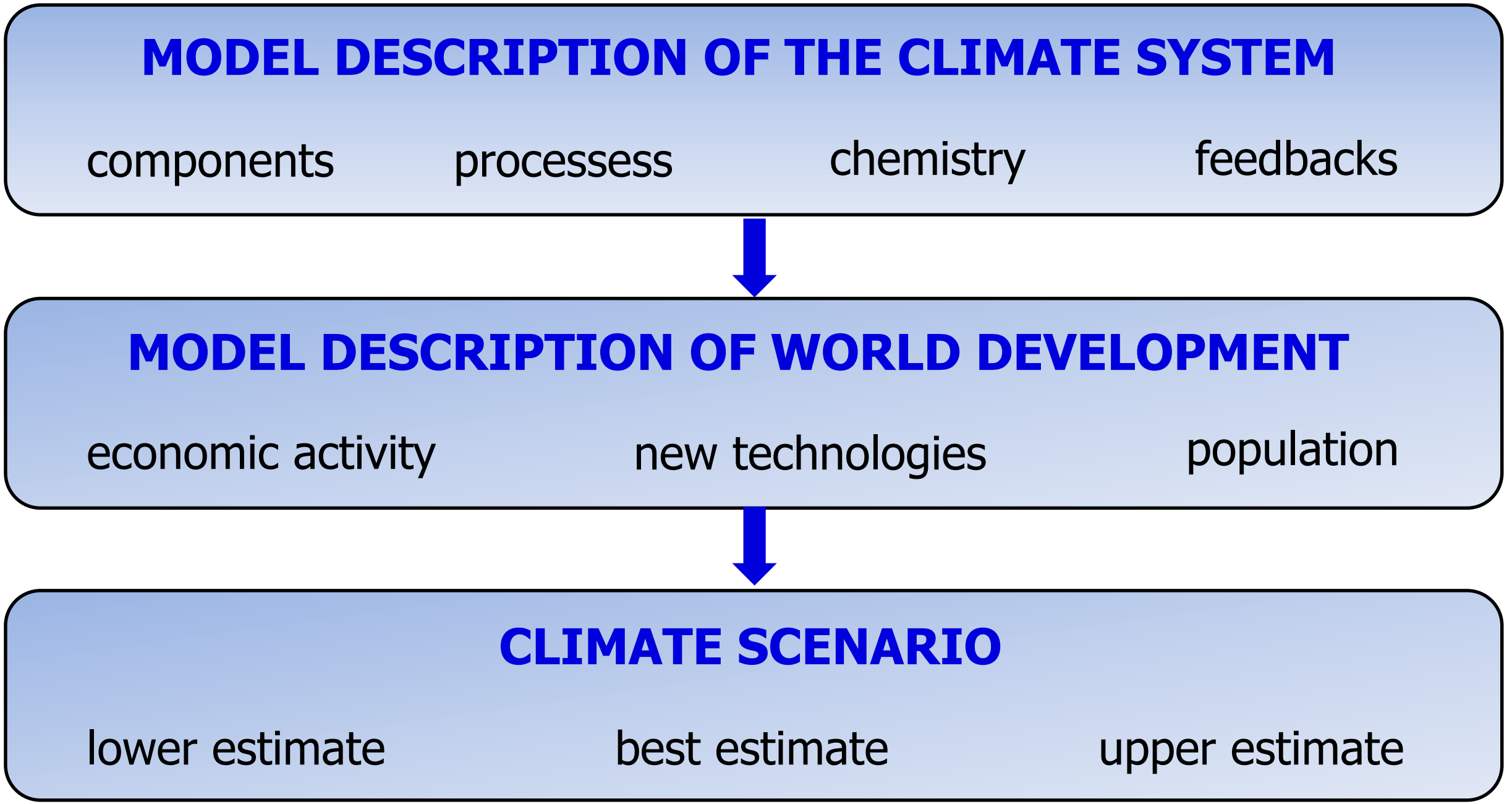
What are emission scenarios, climate models and climate scenarios/projections?

- **Climate models** are used together with emission scenarios to calculate the probable future climate, so-called **climate scenarios/projections**.
- The **climate models** describe how the earth's climate functions, while the **emission scenarios** describe the impact of humans on the environment.
- If the climate models are combined with the emission scenarios, it is possible to predict with a **certain amount of probability** how the climate will be in the future.

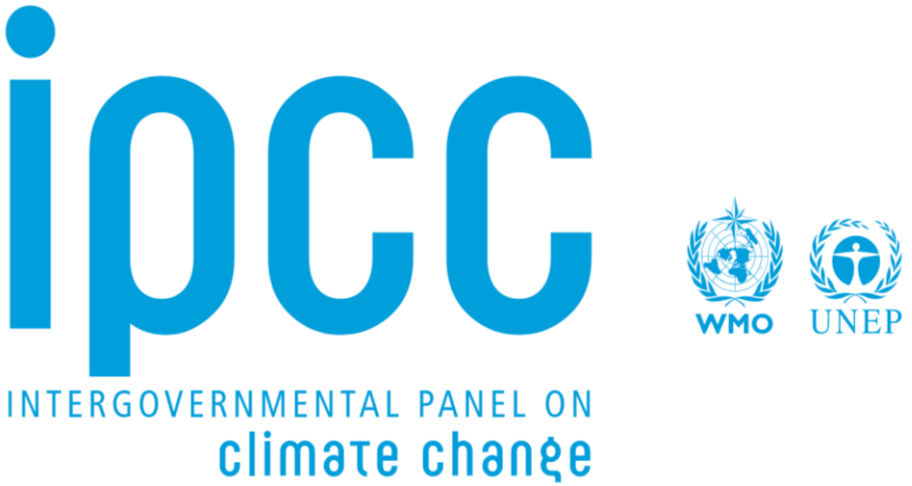
Climate scenarios

- **possible future** of the Earth´s climate
- based on its current observed state and different **GHG emission scenarios**
- potential impacts of **anthropogenic climate change**
- climate projections
- **not a forecast** of the future climate
- **alternative possibilities** of how the future can develop



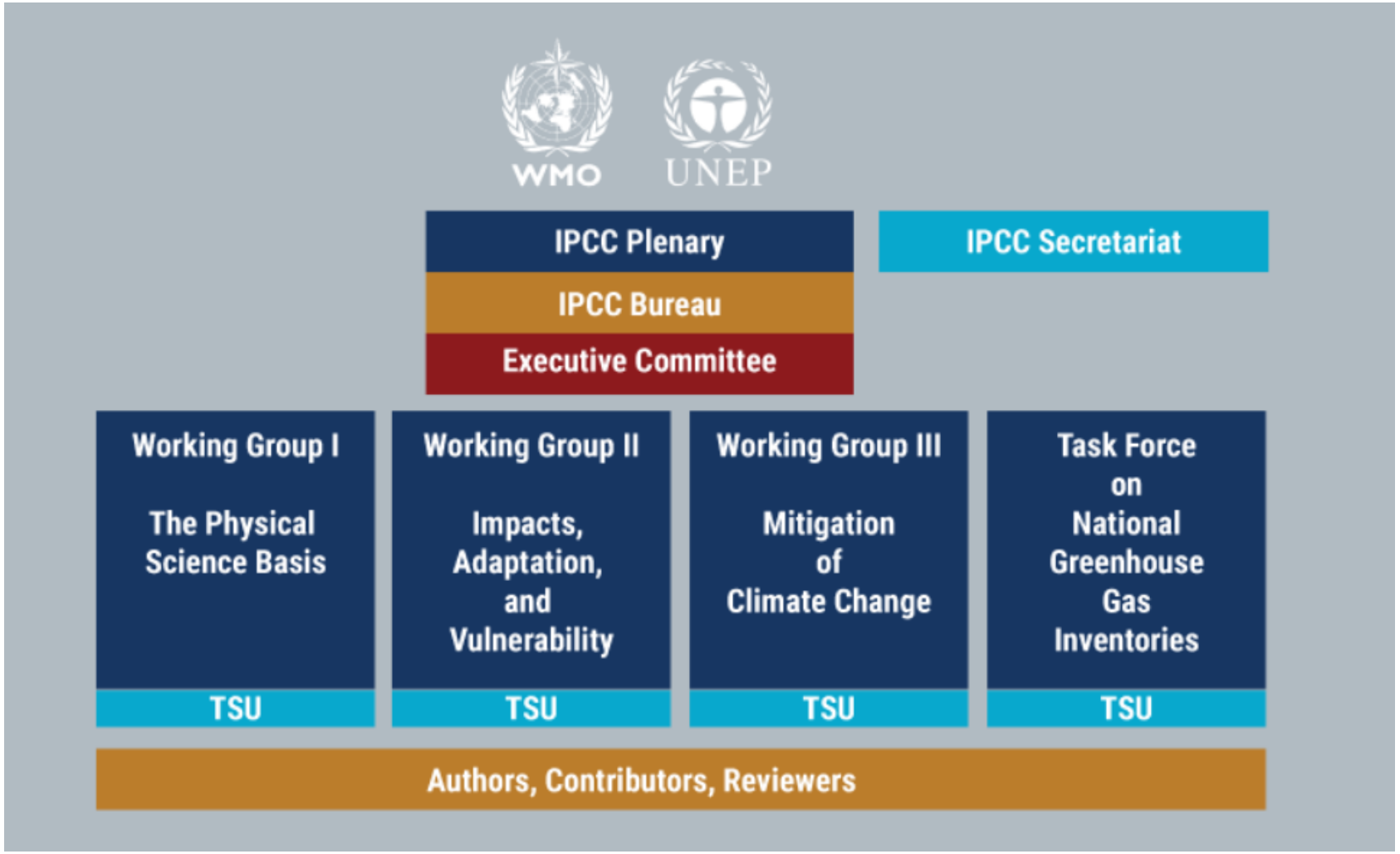

MODEL DESCRIPTION OF THE CLIMATE SYSTEM
components
processess
chemistry
feedbacks
MODEL DESCRIPTION OF WORLD DEVELOPMENT
economic activity
new technologies
population
CLIMATE SCENARIO
lower estimate
best estimate
upper estimate

The Intergovernmental Panel on Climate Change (IPCC)



- the **United Nations** body for assessing the science related to climate change,
- provides **regular assessments** of the scientific basis of climate change, its impacts and future risks, and options for adaptation and mitigation,
- currently has **195 members**.

The Intergovernmental Panel on Climate Change (IPCC)



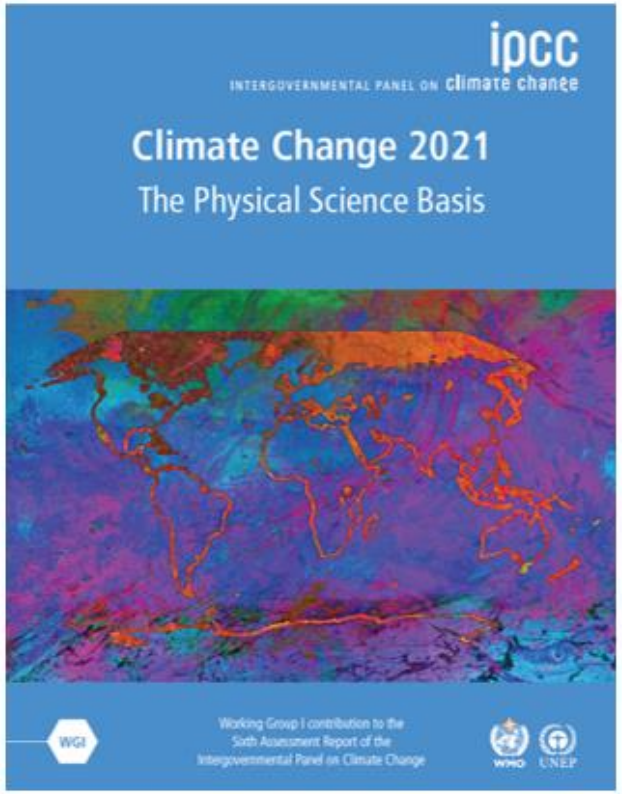
The Intergovernmental Panel on Climate Change (IPCC)

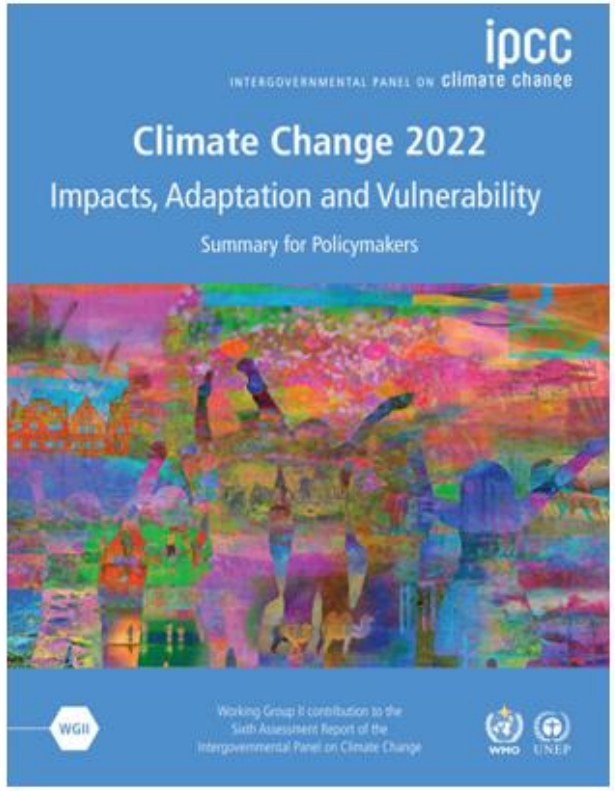
Assessment Reports

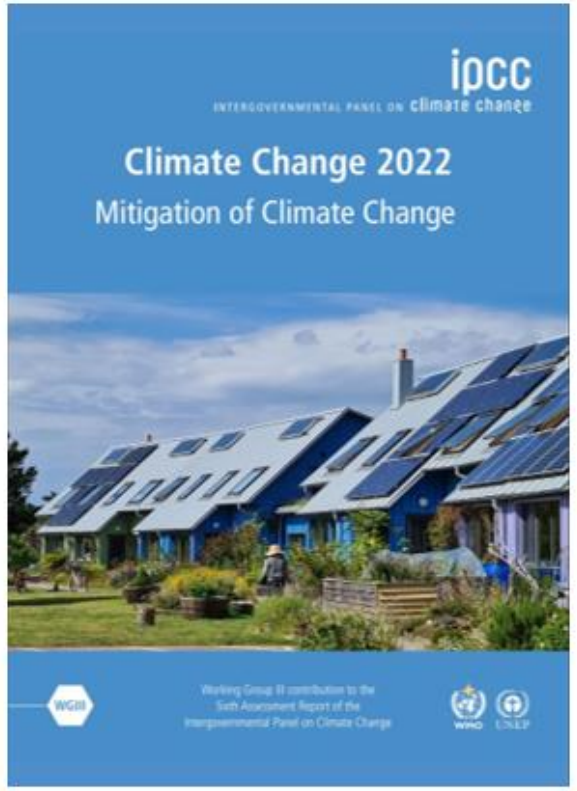
- First Assessment Report (**FAR**, 1990), Supplementary Report (1992)
- Second Assessment Report (**SAR**, 1996)
- Third Assessment Report (**TAR**, 2001)
- Fourth Assessment Report (**AR4**, 2007)
- Fifth Assessment Report (**AR5**, 2013-2014)
- Sixth Assessment Report (**AR6**, 2021-2023)

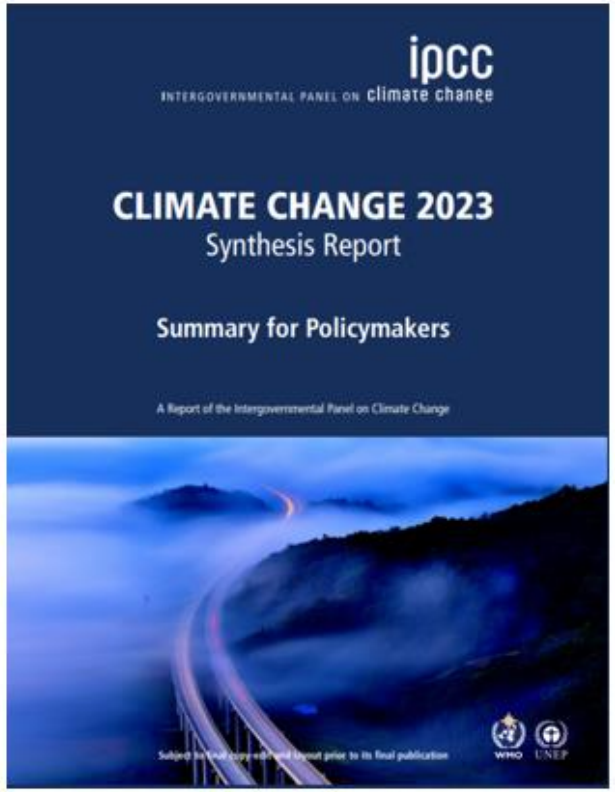
The Intergovernmental Panel on Climate Change (IPCC)

2021–2023: **Sixth Assessment Report (AR6)**







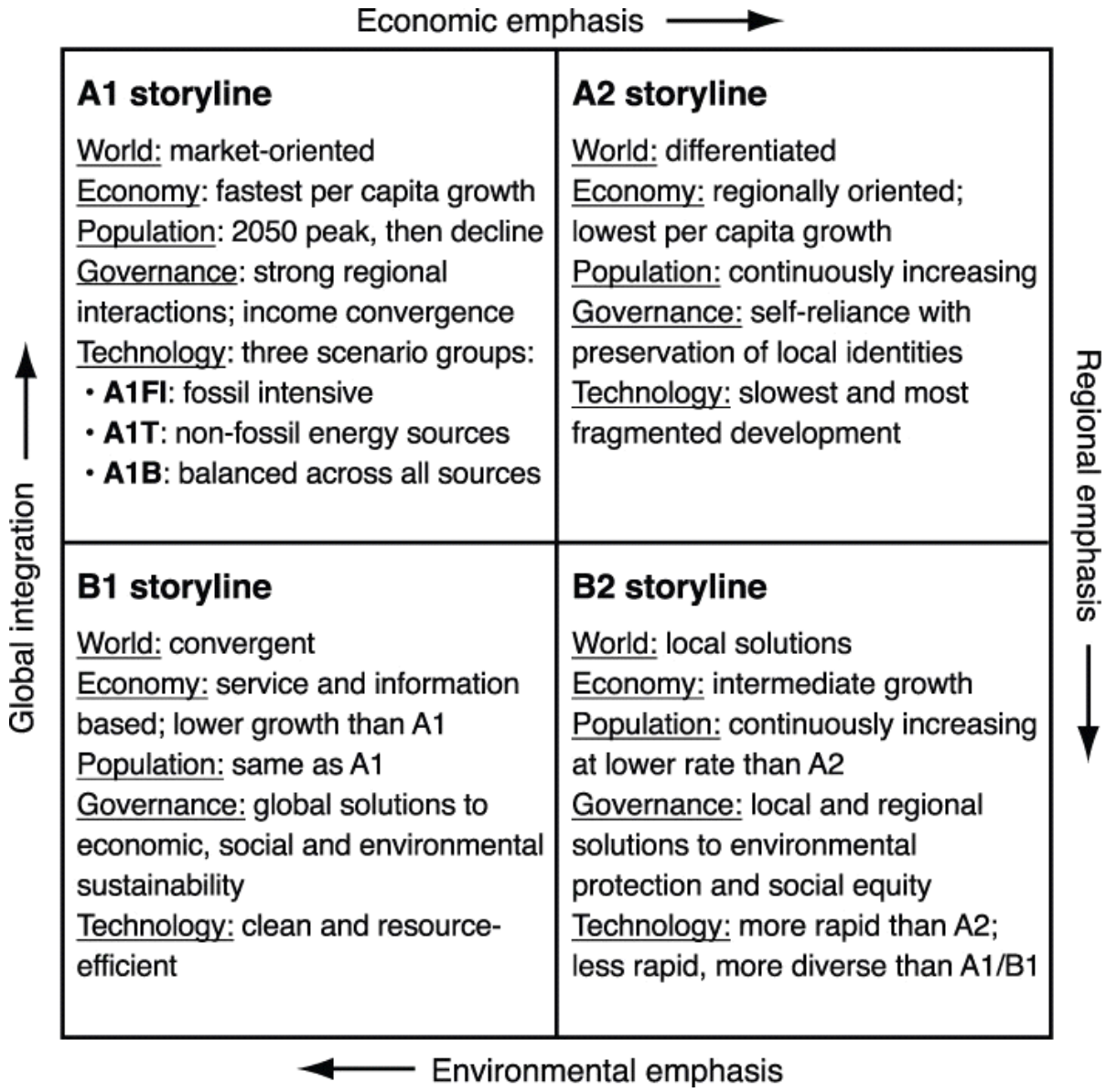


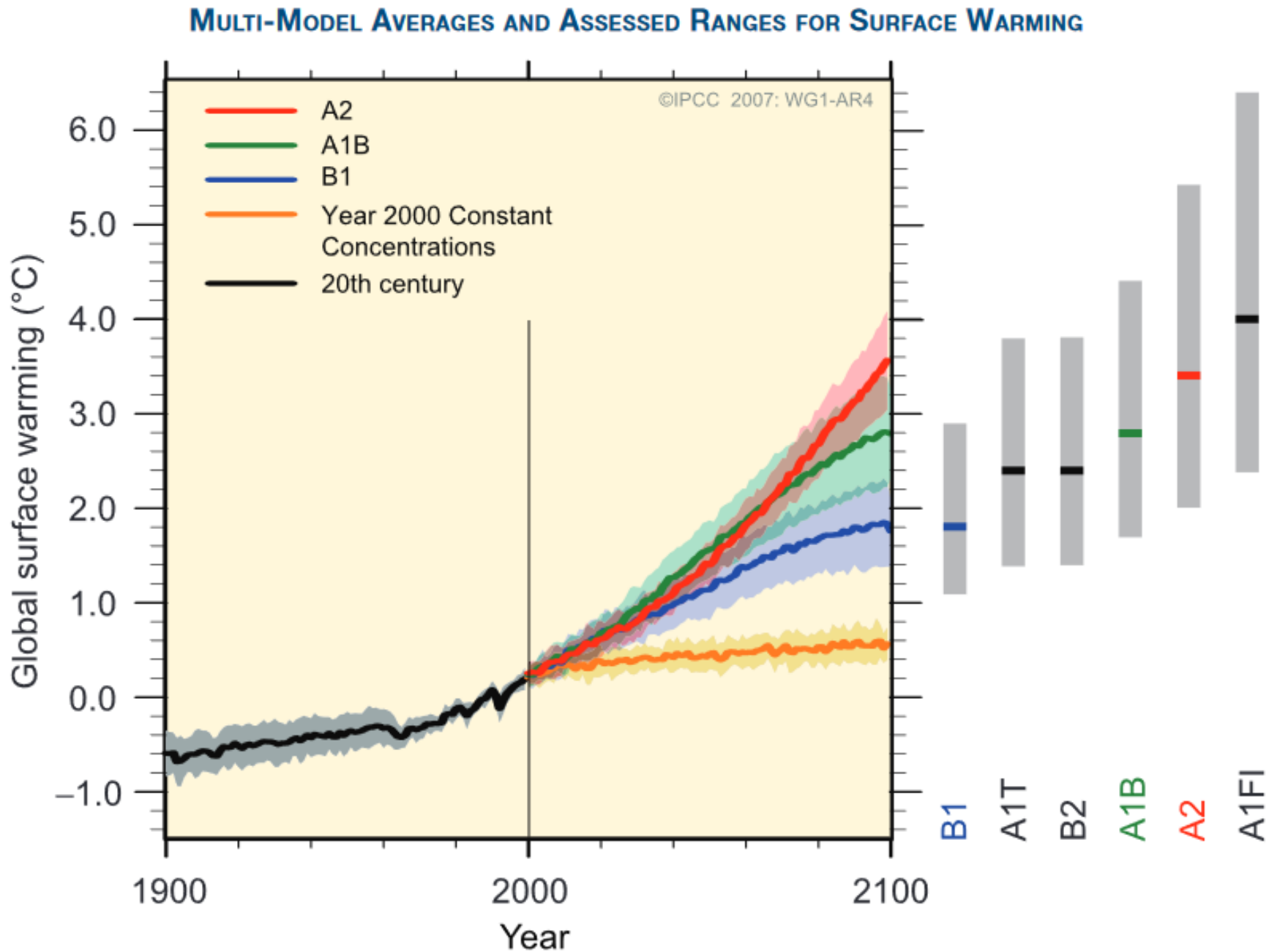
Emissions Scenarios

- possible future development of **GHG concentrations** based on the fulfilment of certain assumptions
- First scenarios: IPCC FAR 1990, new for each AR
- They include the main demographic, ecological and technological influences on **future emissions of GHGs,** sulfur compounds, aerosols, etc.

Special Report on Emissions Scenarios (SRES), 2000

- used in:
  IPCC TAR (2001)
  IPCC AR4 (2007)
- do not take into account any current or future measures to limit GHG emissions





https://www.ipcc.ch/site/assets/uploads/2018/02/ar4-wg1-spm-1.pdf

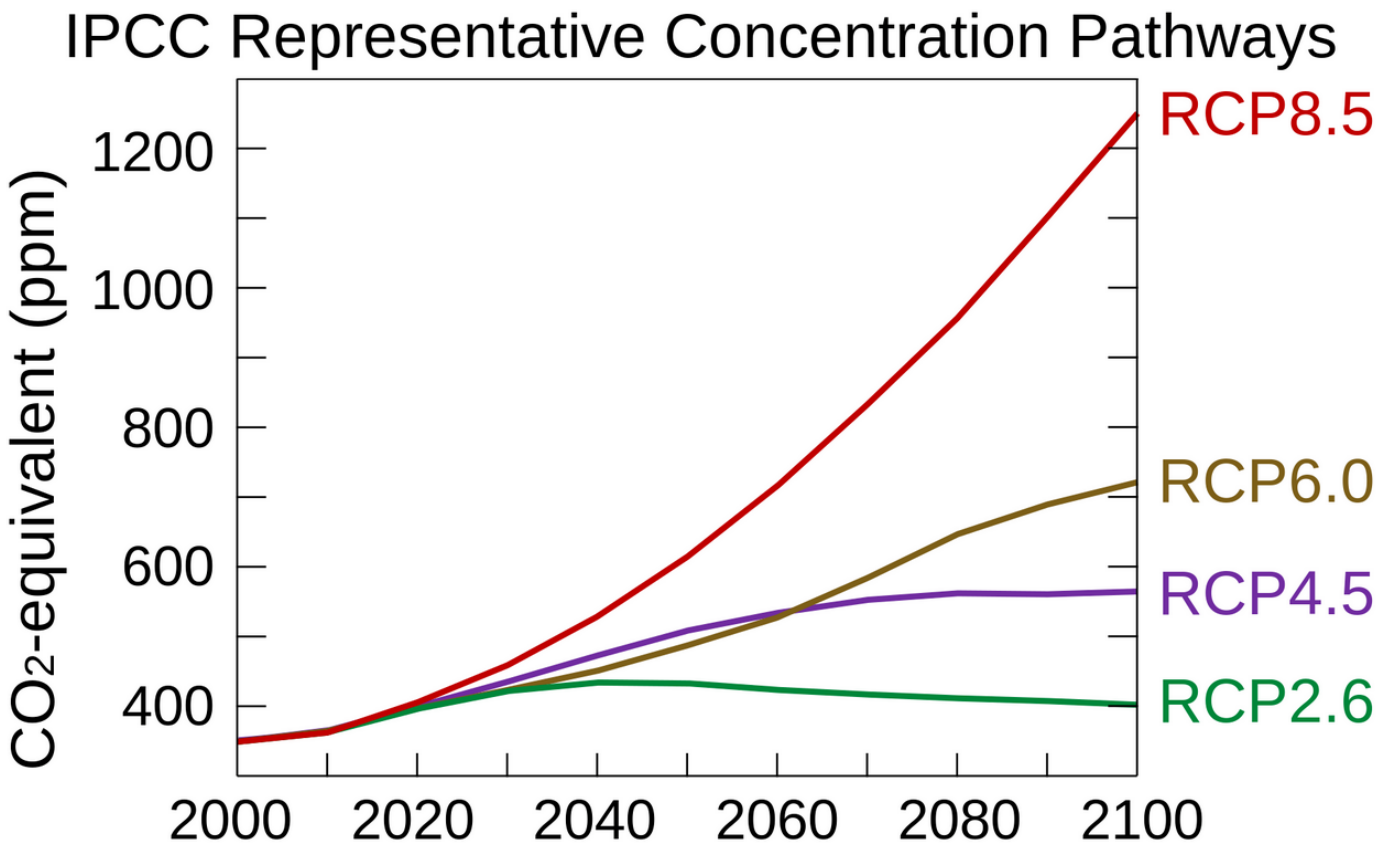
Projected global average surface warming and sea level rise at the and of the 21st century

Table 3.1. Projected global average surface warming and sea level rise at the end of the 21st century. {WGI 10.5, 10.6, Table 10.7, Table SPM.3}

Case	Temperature change (°C at 2090-2099 relative to 1980-1999) [a, d]		Sea level rise (m at 2090-2099 relative to 1980-1999)
	Best estimate	*Likely* range	Model-based range excluding future rapid dynamical changes in ice flow
Constant year 2000 concentrations[b]	0.6	0.3 – 0.9	Not available
B1 scenario	1.8	1.1 – 2.9	0.18 – 0.38
A1T scenario	2.4	1.4 – 3.8	0.20 – 0.45
B2 scenario	2.4	1.4 – 3.8	0.20 – 0.43
A1B scenario	2.8	1.7 – 4.4	0.21 – 0.48
A2 scenario	3.4	2.0 – 5.4	0.23 – 0.51
A1FI scenario	4.0	2.4 – 6.4	0.26 – 0.59

RCP - Representative Concentration Pathways (2011)

- different climate change scenarios, all of which are considered possible depending on the amount of GHGs emitted in the years to come

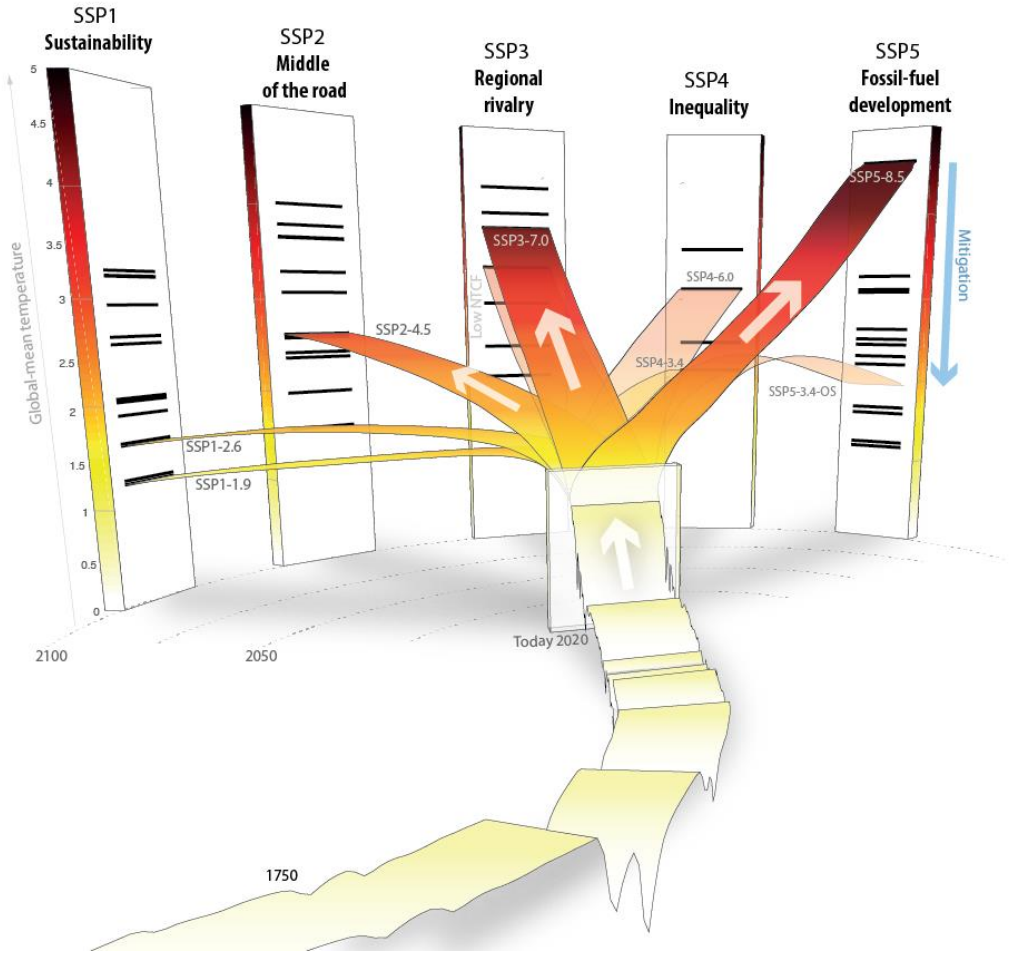


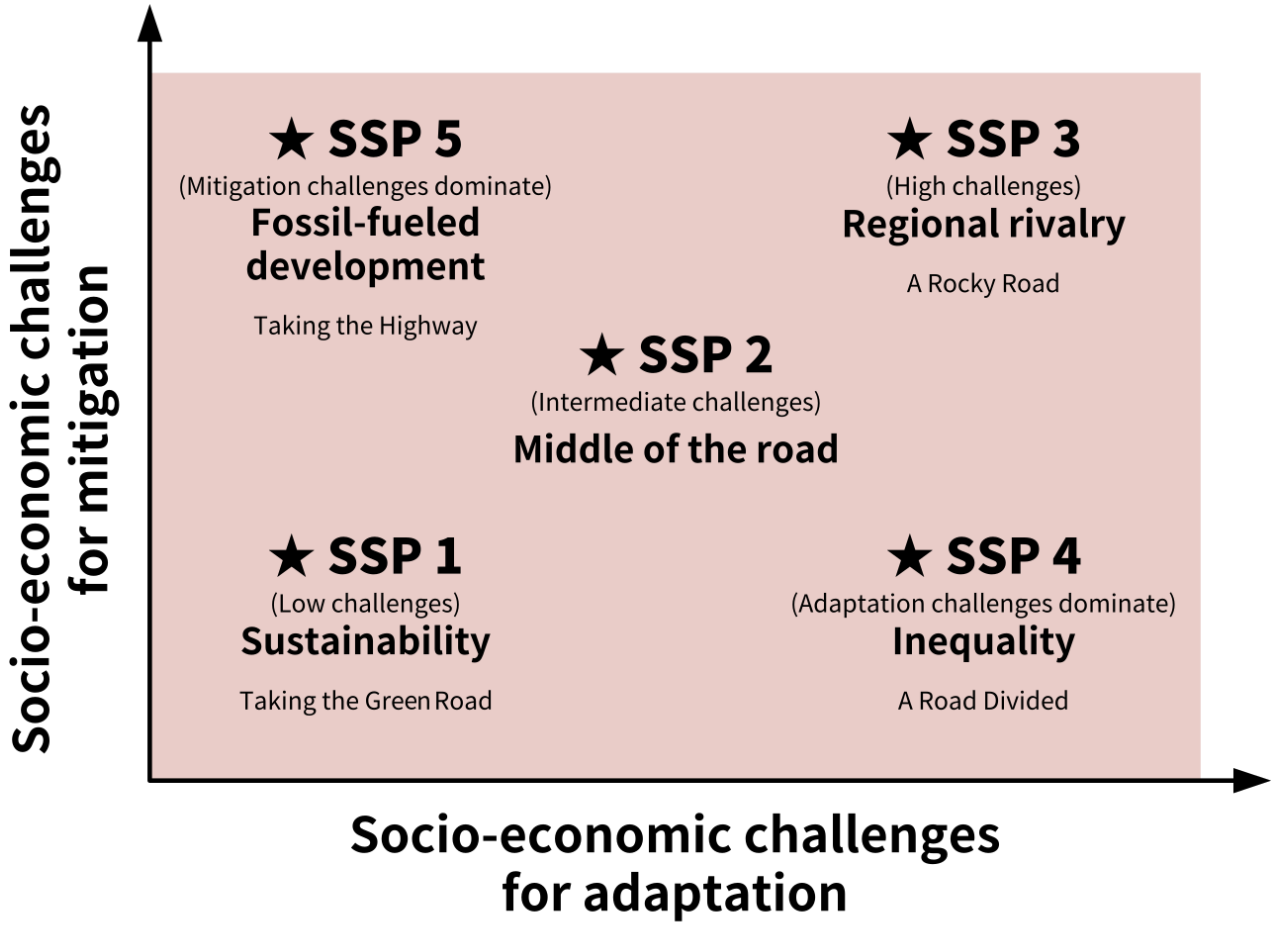
https://tntcat.iiasa.ac.at/RcpDb/dsd?Action=htmlpage&page=welcome

Table SPM.2 | Projected change in global mean surface air temperature and global mean sea level rise for the mid- and late 21st century relative to the reference period of 1986–2005. {12.4; Table 12.2, Table 13.5}

		2046–2065		2081–2100	
	Scenario	**Mean**	***Likely* range[c]**	**Mean**	***Likely* range[c]**
Global Mean Surface Temperature Change (°C)[a]	RCP2.6	1.0	0.4 to 1.6	1.0	0.3 to 1.7
	RCP4.5	1.4	0.9 to 2.0	1.8	1.1 to 2.6
	RCP6.0	1.3	0.8 to 1.8	2.2	1.4 to 3.1
	RCP8.5	2.0	1.4 to 2.6	3.7	2.6 to 4.8
	Scenario	**Mean**	***Likely* range[d]**	**Mean**	***Likely* range[d]**
Global Mean Sea Level Rise (m)[b]	RCP2.6	0.24	0.17 to 0.32	0.40	0.26 to 0.55
	RCP4.5	0.26	0.19 to 0.33	0.47	0.32 to 0.63
	RCP6.0	0.25	0.18 to 0.32	0.48	0.33 to 0.63
	RCP8.5	0.30	0.22 to 0.38	0.63	0.45 to 0.82

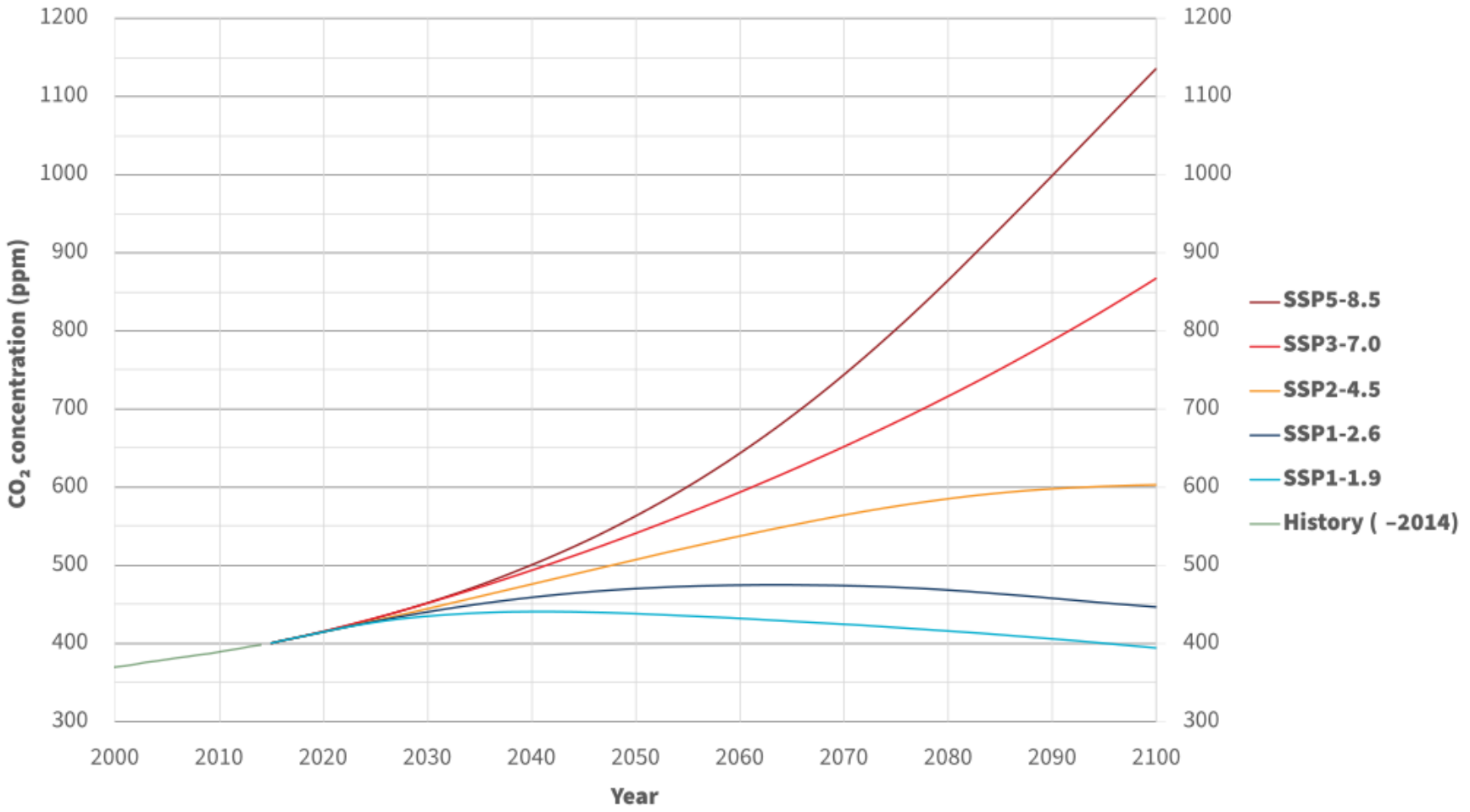
SSP - Shared Socioeconomic Pathways (2021)





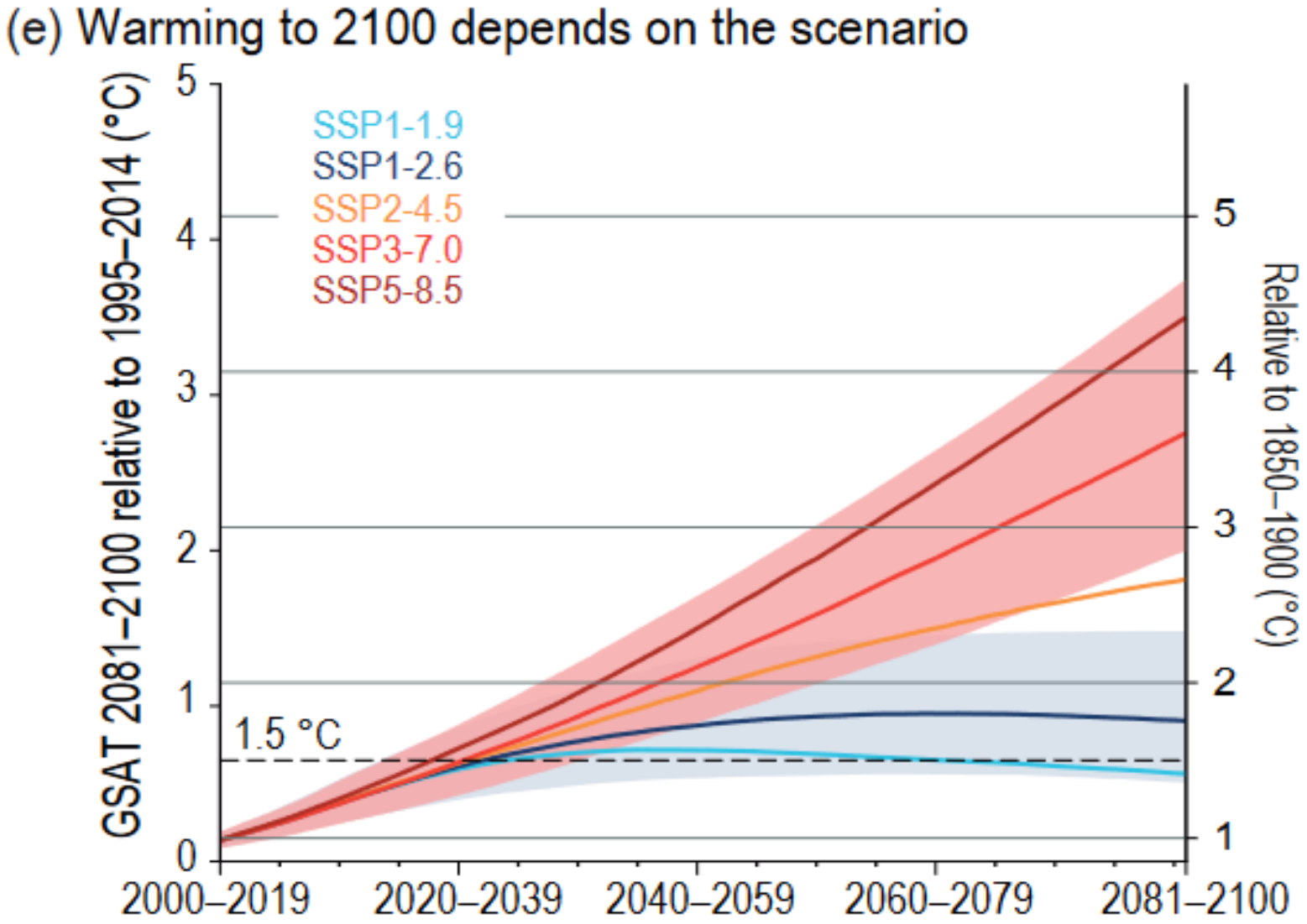
https://en.wikipedia.org/wiki/Shared_Socioeconomic_Pathways

Predicted atmospheric CO_2 concentrations for different SSPs across the 21st century



Climate projections until the end of the 21st century (IPCC, AR6)

Assessed projected change in 20-year running mean global surface temperature for five scenarios



Climate projections until the end of the 21st century (IPCC, AR6)

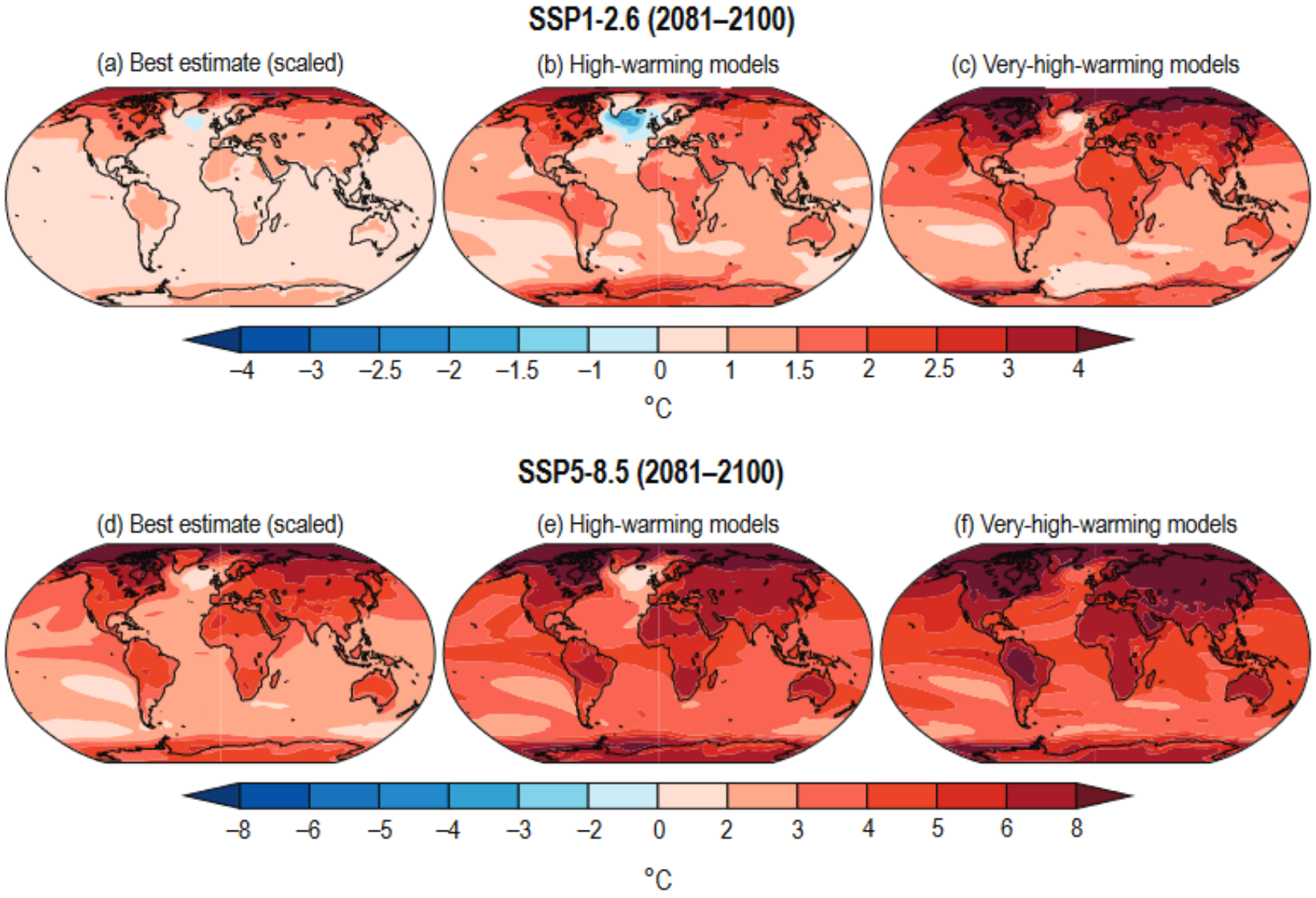
Changes in global surface temperature for selected 20-year time periods

Table SPM.1 | Changes in global surface temperature, which are assessed based on multiple lines of evidence, for selected 20-year time periods and the five illustrative emissions scenarios considered. Temperature differences relative to the average global surface temperature of the period 1850–1900 are reported in °C. This includes the revised assessment of observed historical warming for the AR5 reference period 1986–2005, which in AR6 is higher by 0.08 [–0.01 to +0.12] °C than in AR5 (see footnote 10). Changes relative to the recent reference period 1995–2014 may be calculated approximately by subtracting 0.85°C, the best estimate of the observed warming from 1850–1900 to 1995–2014.
{Cross-Chapter Box 2.3, 4.3, 4.4, Cross-Section Box TS.1}

	Near term, 2021–2040		Mid-term, 2041–2060		Long term, 2081–2100	
Scenario	Best estimate (°C)	*Very likely* range (°C)	Best estimate (°C)	*Very likely* range (°C)	Best estimate (°C)	*Very likely* range (°C)
SSP1-1.9	1.5	1.2 to 1.7	1.6	1.2 to 2.0	1.4	1.0 to 1.8
SSP1-2.6	1.5	1.2 to 1.8	1.7	1.3 to 2.2	1.8	1.3 to 2.4
SSP2-4.5	1.5	1.2 to 1.8	2.0	1.6 to 2.5	2.7	2.1 to 3.5
SSP3-7.0	1.5	1.2 to 1.8	2.1	1.7 to 2.6	3.6	2.8 to 4.6
SSP5-8.5	1.6	1.3 to 1.9	2.4	1.9 to 3.0	4.4	3.3 to 5.7

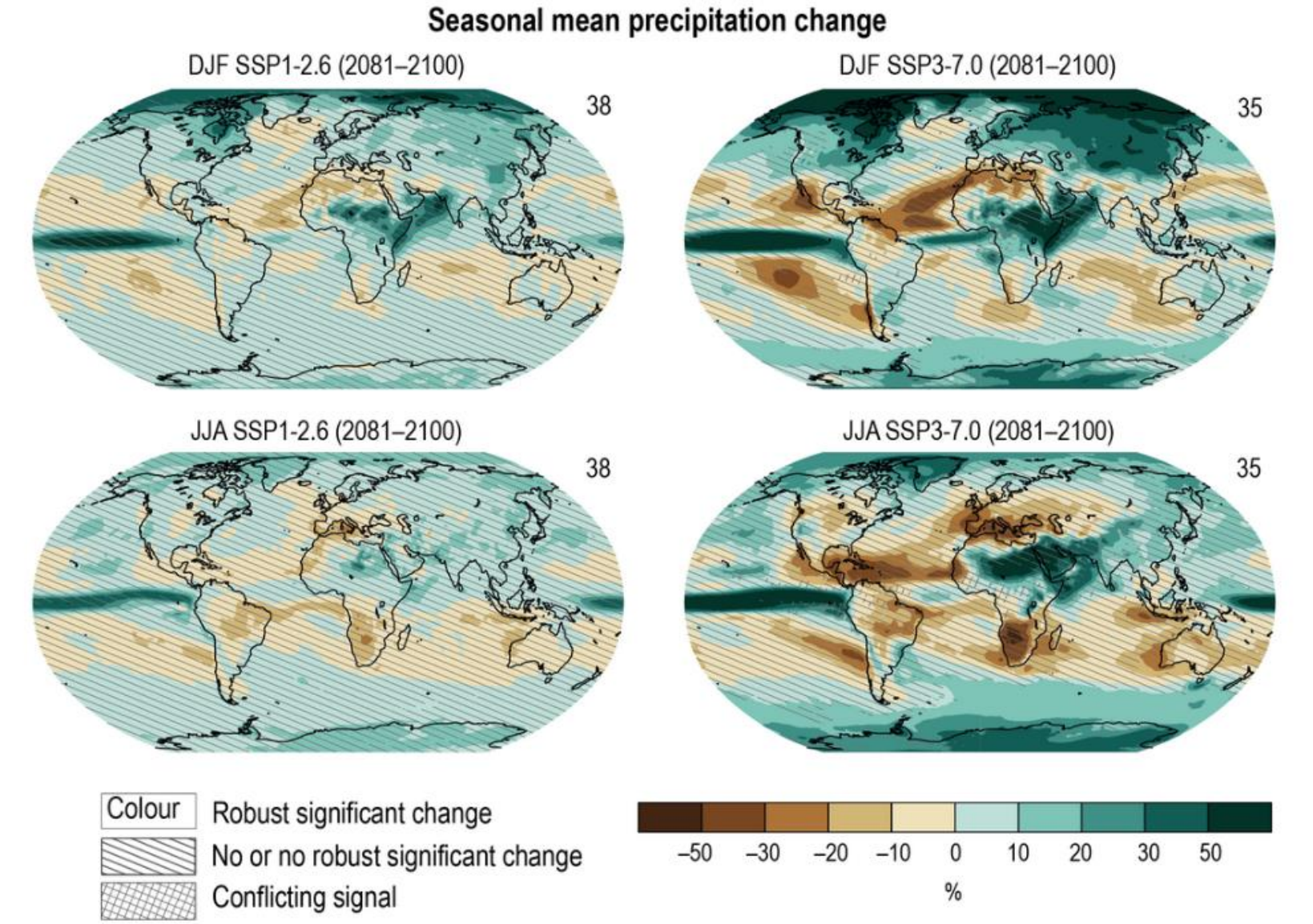
Climate projections until the end of the 21st century (IPCC, AR6)

Global surface temperature estimate for SSP1-2.6 and SSP5-8.5. in 2081–2100 relative to 1995–2014



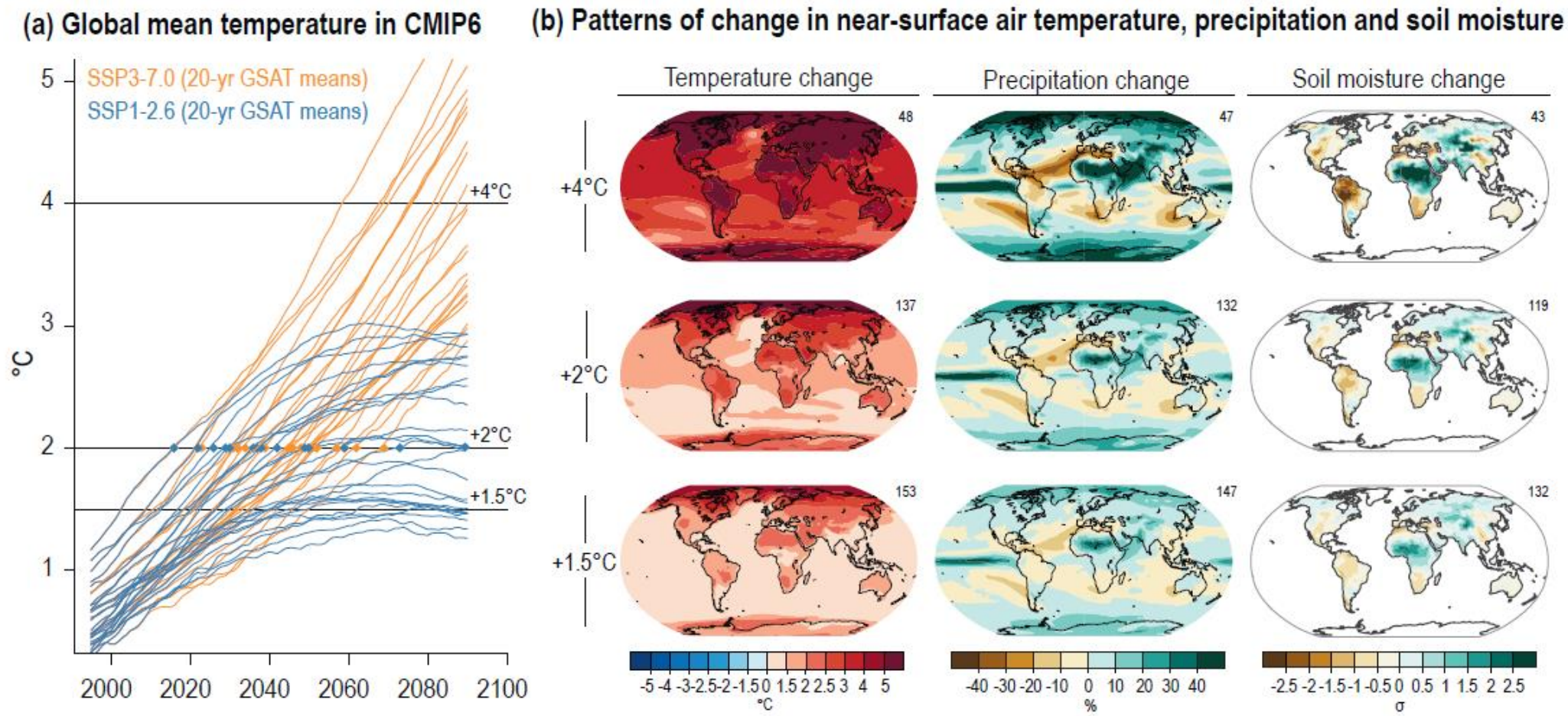
Climate projections until the end of the 21st century (IPCC, AR6)

Seasonal mean precipitation change from SSP1-2.6 and SSP3-7.0 in 2081–2100 relative to 1995–2014

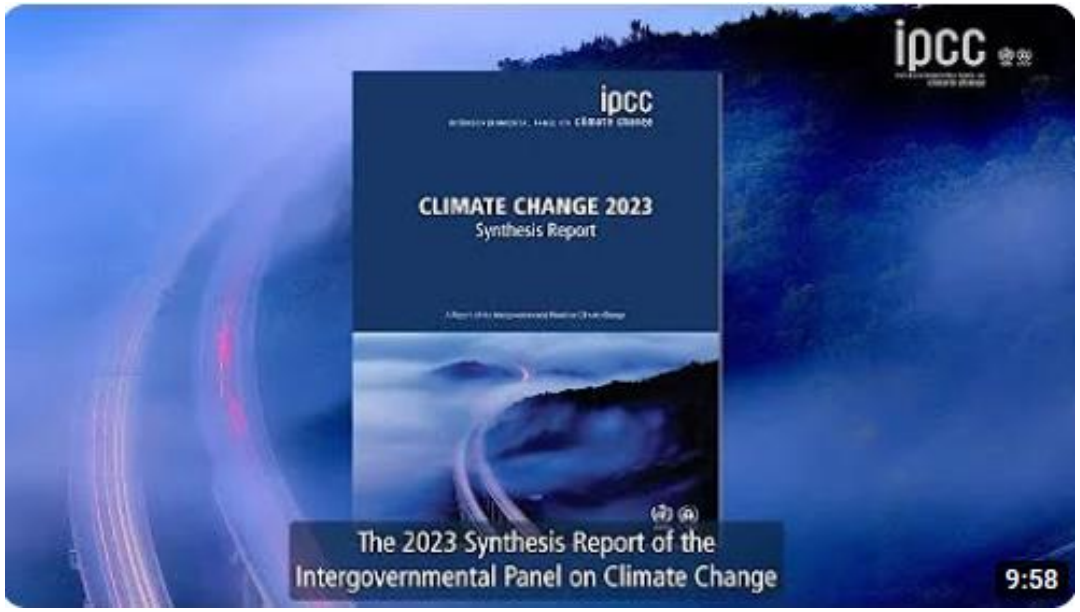


Climate projections until the end of the 21st century (IPCC, AR6)

Scenarios, global warming levels, and patterns of change



AR6 Synthesis Report: Climate Change 2023



The Synthesis Report is based on the content of the **three Working Groups Assessment Reports**: WGI – The Physical Science Basis, WGII – Impacts, Adaptation and Vulnerability, WGIII – Mitigation of Climate Change, and the **three Special Reports**: Global Warming of 1.5°C, Climate Change and Land, The Ocean and Cryosphere in a Changing Climate.

https://www.youtube.com/watch?v=YIFCSZYU2LM

https://www.ipcc.ch/report/ar6/syr/downloads/report/IPCC_AR6_SYR_SPM.pdf

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Thank you for your attention